SCALE MODEL TESTING OF LEACHATE TREATMENT WITH WILLOW STACK TOWER AND EBB-FLOW SYSTEMS

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Environmental Engineering
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ABSTRACT

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ALBERTO FREIRE LÓPEZ: Scale model testing of leachate treatment with Willow Stack Tower and Ebb-flow systems.

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The purpose of this thesis was to design, build, develop and compare two different biofilter systems based on earlier Tampere University of Applied Sciences (TAMK) Research and Development studies concerning the treatment of landfill and compost field leachate with microbial activity in a Willow Stack Tower (WST). The first biofilter is a lab-scale model of a WST, where the leachate is distributed over the willow surface by spraying. The other system experimented with in the study is the Ebb-Flow system, where leachate fills and empties the system through the action of a siphon and aeration.

Experiments were conducted in the laboratories of TAMK, specifically, in the greenhouse. This final thesis is a part of a TAMK Learning Project for Energy and Environmental Engineering; it can be used to develop future projects and practical training opportunities for students.

The synthetic leachate water used in the experiments was prepared according to typical leachate concentration values from Pälkäne Humuspehtoori Ltd. In both the WST and Ebb-Flow systems, the analyzed parameters were temperature, pH, BOD_5, total phosphorus and total nitrogen. The Willow Stack Tower model and the Ebb-Flow system were tested for different flow rates, leachate phosphorus concentrations, BOD_5 values, and total nitrogen concentration.

These results show that the two systems work better at high leachate concentrations. The percentage of nutrients removed from the leachate by the Willow Stack Tower was higher than that of the Ebb-Flow system. Then again, the contaminant removal performance by the willow surface and flow was higher in the Ebb-Flow system than in Willow Stack Tower system.

To conclude, both of these systems could easily be applied in rural areas because they are of a simple design and they require low maintenance. Both systems are also effective methods that could work as a part of leachate treatment process.

Keywords: Willow stack tower, Ebb-flow, biofilter, landfill, leachate, siphon.

Foreword

It has been a real pleasure to take the chance that TAMK University offered me to realize my project. I was very excited at the idea of starting a fresh leachate treatment project with a small-scale laboratory model that was based on earlier research done at TAMK, and having access to completely new and innovative methods of analysis. I enjoyed the chance to work with partners from different countries. It has been a big challenge and an even greater opportunity for me. I am delighted and very proud, that this project can be further used in teaching future students.

I would like to especially thank my supervisor, Seija Haapamäki. She has shown great dedication and placed confidence in my talents. I would also like to thank Eeva-Liisa Viskari for her great enthusiasm. She always showed amazing interest in developing new ideas and methods for this project.

I would like to mention the laboratory staff, who kindly offered me everything that I needed. I would also like to thank the TAMK Environmental Engineering students for their outstanding support.

Of course I could not forget my lab mates: I am grateful to Gerbrand Grobler, for the assistance and ideas provided during the construction of the whole project; Catherine Mburu for her company during laboratory hours; and Cláudia Zambeze for the long talks in the laboratory and all the time spent on new analytical methods.

Thank you to all the friends I have met in Tampere, because they helped me to improve my English skills and above all, helped me feel at home.

Finally, thanks to my family, friends and girlfriend, for the efforts they have made to support me in the project during my time in Tampere.

Tampere March 2012

Alberto Freire López

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LIST OF SYMBOLS

ABS	Acrylonitrile butadiene styrene
BOD	Biochemical oxygen demand
BOD_5	Biochemical oxygen demand during 5 days
C	Carbon
c	Concentration
COD	Chemical oxygen demand
DO	Dissolved oxygen
EF	Ebb-flow system
F	Flow
H	High of the tank
K	Potassium
MSW	Municipal solid waste
N	Nitrogen
NH^{+}_{4}—N	Ammonia nitrogen
NREF	No removal Ebb-flow system
NRLC	No removal at high concentration
NRLC	No removal at low concentration
NRLF	No removal at high flow
NRLF	No removal at low flow
NRWST	No removal Willow stack tower
NS	No significant
Number + N	Normal concentration
Ø	Diameter
Ɵ	Mass flow density removed
P	Phosphorus
P + number	Pump

PAOs	Phosphorus accumulating organisms
pH	Logarithmic H^+ concentration
S	Sulphur
t	Time
T^a	Temperature
TAN	Total ammonia nitrogen
TN	Total nitrogen
TP	Total Phosphorus
WST	Willow stack tower
Zn	Zinc

1. INTRODUCTION

1.1. Landfill leachate problematic

In most of countries, sanitary landfill is nowadays the most common way to final deposition of municipal solid waste (MSW). The Figure 1 shows waste management shares in EU countries:

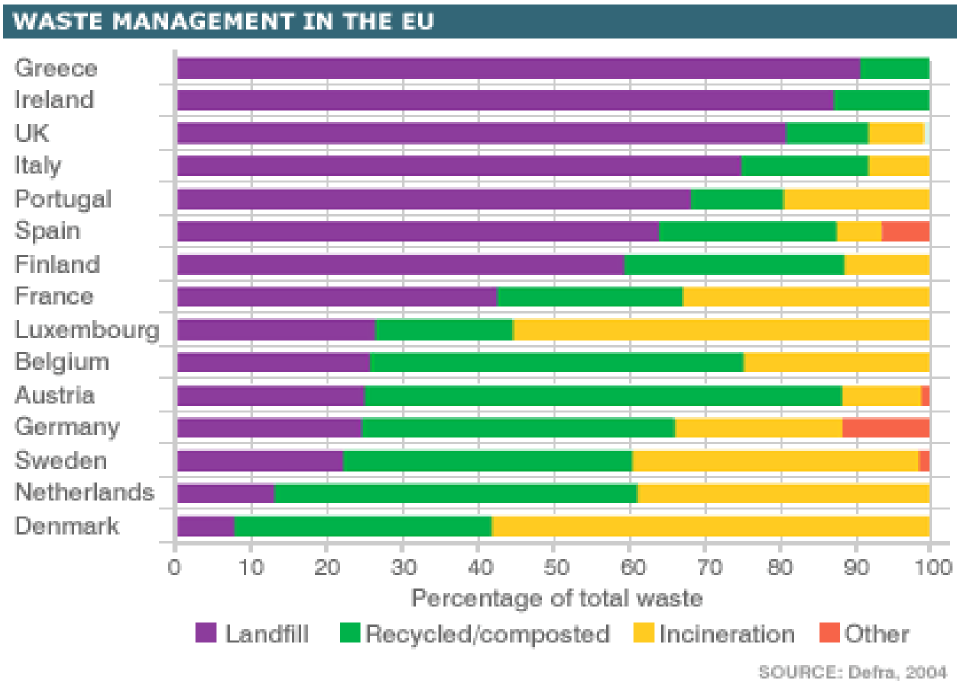


FIGURE 1. Waste management shares in EU countries.
(http://news.bbc.co.uk, 2005)

Leachate from landfills is one of the most damaging sources of pollution on the surrounding environment (Ritzkowski et al., 2006; Bilgili et al., 2007); this landfill leachate is due to the high concentration of contaminants, its affects to the quality of the air, soil and water. (Prantl et al., 2006). In spite of many advantages, generation of heavily polluted leachate, presenting significant variations in both volumetric flow and chemical composition, constitutes a major drawback. Year after year, the recognition of landfill leachate impact on environment has forced authorities to fix more and more stringent requirements for pollution control. In the Figure 2 the leachate formation is presented briefly.

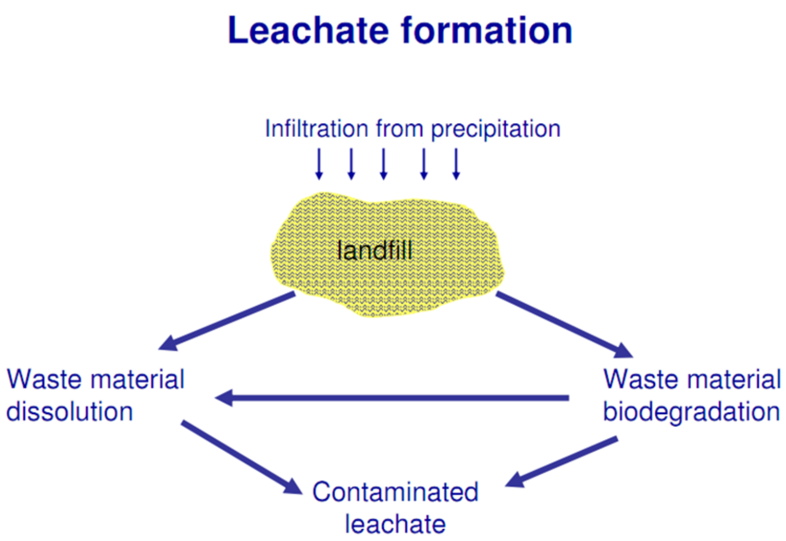


FIGURE 2. Leachate formation. (http://news.bbc.co.uk, 2005)

Leachate can be treated by chemical, physical and biological methods, and by different combinations of these methods. The biological treatment is effective for the removal of BOD, NH^{+}_{4}—N and heavy metals, when recent landfill leachate is treated. (Zhi-Yong Han et al., 2010)

1.2. Biofilters

It is well known that aged refuse has a high porosity and specific area. In these aged refuse, over time, bacteria become to acclimate at high concentrations. (Zhao et al., 2006; Shi et al., 2007) Using aged refuse to leachate treating is a good option. In this case, biofilters are a low-cost alternative. (Jokela et al., 2002)

1.2.1 Chemical parameters

One of the most problematic chemical parameters in leachate treatment is BOD, total nitrogen and total phosphorus. For this reason this parameters were analyzed in this final thesis.

1.2.1.1 Biochemical Oxygen Demand

In the WST from Pälkäne Ruokola Biochemical Oxygen Demand (BOD_5) is removing with higher efficiency (around 80% removal efficiency) than TN and TP (around 70% removal efficiency) (Kati Hepokorpi et al., 2010). Also the BOD_5 influent concentration value is ten times higher than TN and TP concentration values. The reason for this removal efficiency for carbon is because normal aerobic bacteria carbon composition is close to 50%, it can be seen in Table 1.

TABLE 1. Normal bacteria, chemical composition. (Bruce E. Rittmann. 2002, 14)

Chemical composition	
Constituent	Percentage (%)
Organic	90
C	45-55
O	22-28
H	5-7
N	8-13

1.2.1.2 Total Nitrogen

The slow leaching of nitrogen from solid waste in landfills, like result of high concentrations of ammonia in the landfill leachate, may last for several decades. Nitrogen removal is a good way to prevent rivers and lakes eutrophication. (J.P.Y. Jokela et al., 2002). Therefore total nitrogen (TN) is used as indicator value in this final thesis. In Figure 3 is shown the different reactions to remove total nitrogen.

NITRIFICATION

$$\mathrm{NH_4^+} + \frac{3}{2}\mathrm{O_2} \xleftrightarrow{microorganism} \mathrm{NO_2^-} + 2\mathrm{H^+} + \mathrm{H_2 0}$$

$$\mathrm{NO_2^-} + \frac{1}{2}\mathrm{O_2} \xleftrightarrow{microorganism} \mathrm{NO_3^-}$$

$$\mathrm{NH_4^+} + 2\mathrm{O_2} \xleftrightarrow{microorganism} \mathrm{NO_3^-} + 2\mathrm{H^+} + \mathrm{H_2 0}$$

DENITRIFICATION

$$\frac{1}{5}\mathrm{NO_3^-} + \frac{6}{5}\mathrm{H^+} + e^- \xleftrightarrow{microorganism} \frac{1}{10}N_2 + \frac{3}{5}\mathrm{H_2 0}$$

BACTERIA AUTOCONSUPTION

$$\mathrm{C_5}H_7NO_2 + 5\mathrm{O_2} \xleftrightarrow{microorganism} CO_2 + NH_3 + 2\mathrm{H_2 0}$$

FIGURE 3. Nitrification, denitrification reactions. (Fernández M., 2010)

Temperature impact on the fixed film nitrification rate at 20 ºC was 1.108% per ºC when oxygen is limited. When there is enough oxygen the value increase until 4.275% per ºC. (Songming Zhu et al., 2002)

pH influence over nitrification in submerged biofilters range of 5.0-9.0 produce a 13% increase on the nitrification yield when pH increase in one unit. (F. Fdz-Polanco et al., 1996). Diagram for nitrogen removal processes is shown in Figure 4.

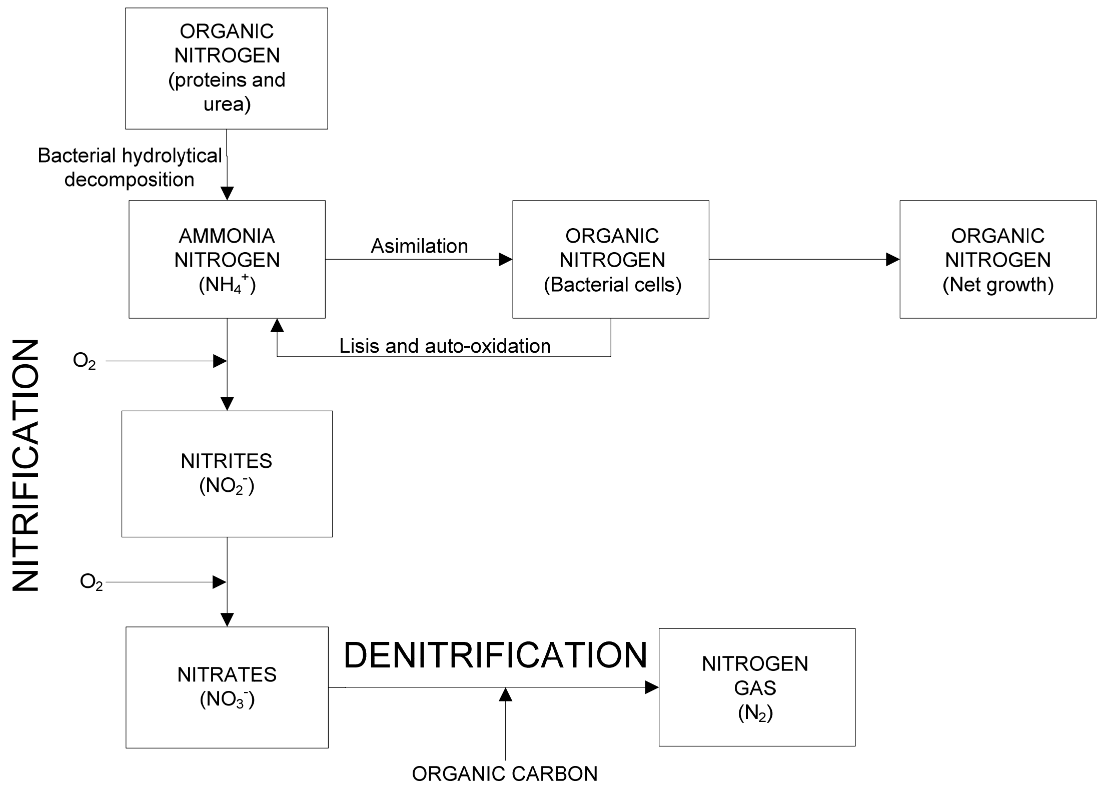


FIGURE 4. Diagram nitrogen removal processes. (Fernández, M., 2010)

1.2.1.3 Total Phosphorus

To ensure that the microorganisms accumulate phosphorus, the biofilter system has to be on alternating conditions of aeration/no aeration.

"In anaerobic condition, Phosphorus accumulating organisms (PAOs) take up easily biodegradable substrate quickly from the bulk and store them in form of polyhydroxyalkanoates accompanied with degradation of polyphosphate and consequent release of phosphorus. In the subsequent aerobic condition, PAOs grow aerobically and take up phosphate from the bulk to recover intracellular polyphosphate level by using polyhydroxyalkanoates stored anaerobically as carbon and energy sources". (Zheng Bei et al., 2008) Phosphorus removal reaction is shown in Figure 5.

$$n_1\text{Organic materia} + n_2\ O_2 + n_3 NH_3 + n_4 PO_4^{3-} \xrightarrow{microorganism} n_5\ \text{New cells} + n_6 CO_2 + n_7 H_2O$$

FIGURE 5. Phosphorus removal reaction. (Fernández, M., 2010)

1.2.2 Willow stack tower

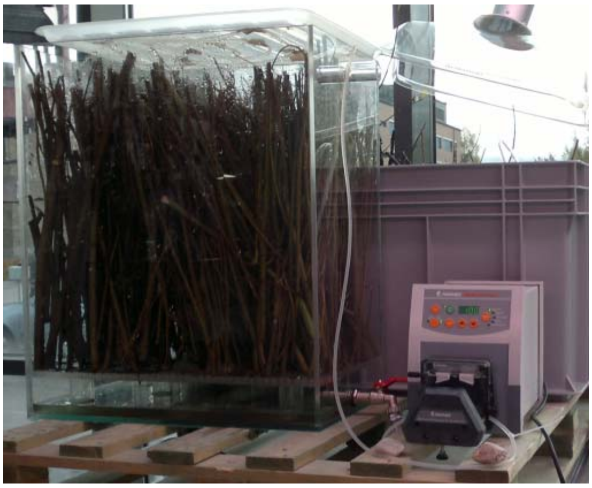
Willow stack tower is being used in some rural places in Finland, like Vaasa and Pälkäne, to remove contaminants from landfill leachate and leachate created on compost field. This WST consisted of a wooden frame with three floors filled with willow stacks and of a pool located underneath the willow stack tower. In regular use during summer 2009 in Pälkäne, leachate was treated in the tower until it was satisfactory in reduction of unwanted substances and was then transferred to the septic tanks for sedimentation from where it continued to the soil filtration and finally to the water bodies. (Kati Hepokorpi et al., 2010). Willow stack tower, Pälkäne (Ruokola) is shown in Picture 1.

PICTURE 1. Willow stack tower, Pälkäne (Ruokola). (Photo: Muñoz & Lopez, 2011)

With this study of Pälkäne (Ruokola) WST system, it can be predicted that the system works better at high influent concentrations. This is pilot WST plant was analyzed at TAMK laboratory; the idea was to create a quite similar system like in Pälkäne (Ruokola). The design is done with some values of the Pälkäne (Ruokola) water treatment plant (45.01 Kg BOD/1000 m^2*d); And the concentration of the leachate water is done with quite similar values (Kati Hepokorpi et al.,2010). Leachate composition from Pälkäne (Ruokola) is shown in Table 2 and in Picture 2 is shown Willow stack tower pilot plant in TAMK greenhouse.

TABLE 2. Leachate composition from Pälkäne (Ruokola).

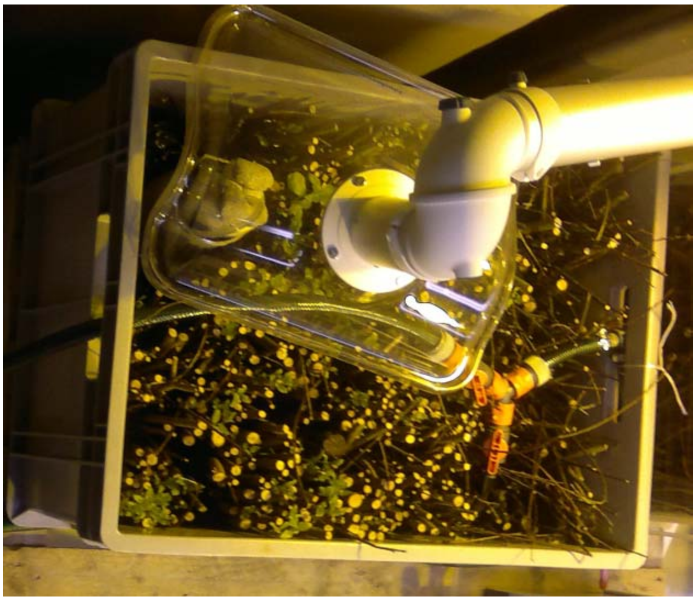
Compound	Concentration (mg/l)
BOD_5	400
NH_4^+	40
PO_4^-	20



PICTURE 2. Willow stack tower pilot plant, TAMK greenhouse.
(Photo: Alberto Freire, 2011)

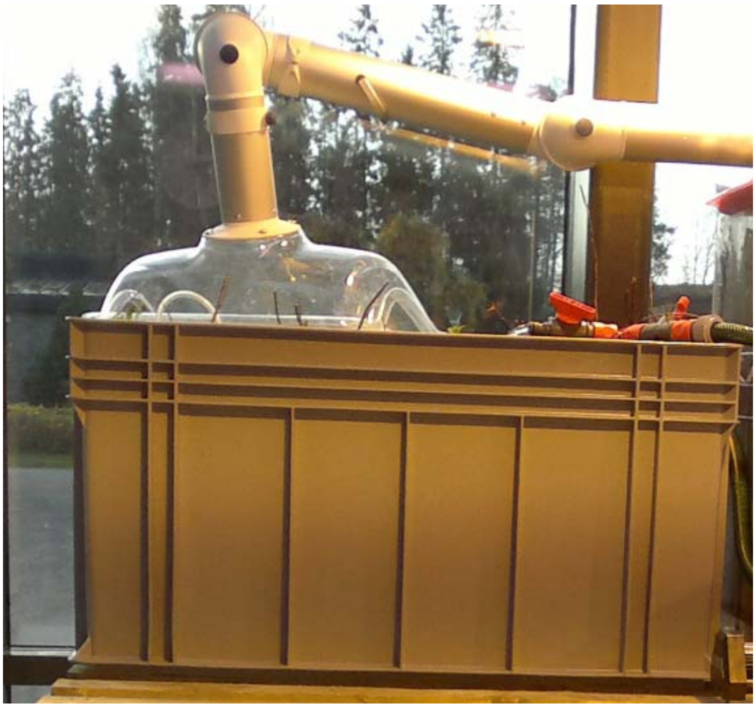
1.2.3 Ebb-flow system

Ebb-flow system is a new system working with the same idea as WST. It is based on the idea of maximizing the surface area of willow branches which are acting as a growing media for the microbes which use the leachate contaminants as their nutrients. Willow stacks distribution in Ebb-flow system pilot plant is shown in Picture 3.



PICTURE 3. Ebb-flow pilot plant, willow distribution, TAMK greenhouse.
(Photo: Alberto Freire, 2011)

There are main differences between WST and EF systems: WST is an open continuous system and EF is a semi-close system which operates in batches. Other difference is that the aeration is arranged by the siphon in EF and for WST is a spray system. In the EF system does not need a flow distribution system, like spray system in the WST. Front of Ebb-flow pilot plant is shown in Picture 4.



PICTURE 4. Front Ebb-flow pilot plant, TAMK greenhouse.
(Photo: Alberto Freire, 2011)

In WST and EF system the biofilm formation is developed in different steps: attachment, colonization and growth. The steps of biofilm formation are shown better in Figure 6.

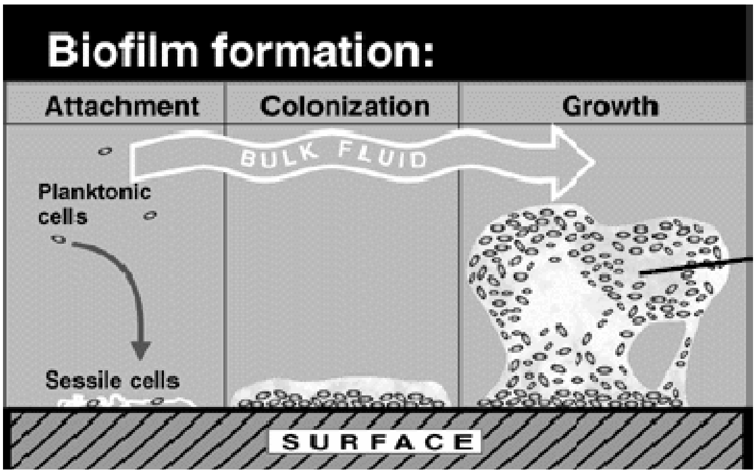


FIGURE 6. Biofilm formation. (Rittmann, B. E. 2002, 208)

2. OBJECTIVES

There are two objectives in this project. The main purpose was the design, construction, analysis, comparison and development of two different aerobic fixed biofilter systems. (Ebb-flow and Willow stack Tower); improving effluent landfill leachate quality was the goal. Another aim was comparing the results obtained in the Willow Stack Tower pilot plant, with Pälkäne (Ruokola) system. (Willow stack tower results from test runs during summer, 2009; Hepokorpi & Khelia, 2010).

3. DESIGN BASIS OF THE SYSTEM

3.1. Calculation references

Despite a large degree of diversity within biofilm processes, certain features remain remarkably consistent. Paramount among these common features is the BOD flux employed to achieve satisfactory effluent quality for wastewater treatment. For almost all biofilm processes, the steady-state BOD flux falls in the range of 2 to 10 Kg BOD/1000 m^2*d. (Bruce E. Rittman et al. 2002, 435)

3.1.1 Willow stack tower

Willow stack tower system works better at higher contaminant concentration; so with the WST from Pälkäne (Ruokola) the value calculated is 45 Kg BOD/1000 m^2*d. (Kati Hepokorpi et al., 2010). This value is the calculation base of scale pilot plant flow rate.

3.1.2 Ebb-flow system

In this case, there are not any values to start to design. This system is completely new, so the value with which do the design and construction of the system is an estimated value of retention time. Retention time value must be long enough, that the microorganisms can perform their enzymatic function, but short enough so that they have enough oxygen to perform their functions properly. Several retention times were tested. The shorted retention time was 15 minutes per cycle and the longest one was 30 minutes.

3.2. Calculations

The initial volume of the tank was predetermined by the available tanks at TAMK laboratories. With this initial volume values calculations are realized.

3.2.1 Willow stack tower

The Willow stack tower Volume was 75 litres, filled with willow branches. The surface average of one branch is known:

$$A_b = 2 * \pi * r^2 + 2 * \pi * r * h \quad (1)$$
$$A_b = 158.6\ cm^2 = 0.01586\ m^2$$
$$r = \text{Average radius of one branch} = 0.5\text{cm}$$
$$h = \text{Average high of branches} = 50\ \text{cm}$$

With the dimensions of the tank, the calculation of the total willow branch surface in the WST is shown below:

$$A_t = A_b * \frac{W_{\tan k} * L_{\tan k}}{(D_b)^2} = 158.6cm^2 * \frac{30cm * 50cm}{(1cm)^2} = 237975cm^2 \cong 23.80m^2 \quad (2)$$

$$A_{rt} = A_t * \eta = 23.80m^2 * 0.24 = 5.70\ m^2 \quad (3)$$

$A_{rt} =$ Real total area of branches
$A_t =$ Total area of branches
$W_{\tan k} =$ Width of the tank= 30 cm
$L_{\tan k} =$ Length of the tank= 50 cm
$D_b =$ Diameter of one branch= 1 cm
$\eta_{WST} =$ Efficiency of the surface WST = 0.24

The problem with the branches is that in the WST branches have enough space between them. The experimental count is 24 branches in 100 cm^2. So, real efficiency of the surface is 24 % respect ideal value. In an idea surface of 10*10 cm count the number of branches out there. The average diameter of a branch is 1 cm, so in 100 cm^2 there are

100 branches, if they were ideally placed. So it is necessary to apply efficiency of the surface, 0.24. Real amount of branches in Willow stack tower are shown in Picture 5. The red 10*10 cm square in Picture 5 shows where the branches were counted for surface efficiency.

PICTURE 5.Willow stack tower, real amount of branches, TAMK greenhouse. (Photo: Alberto Freire, 2011)

With the total willow branch area and the value from WST from Pälkäne (Ruokola) 45 $Kg_{BOD}/1000\ m^2*d$ and the BOD concentration in leachate water, the calculation of the flow goes as follows:

$$F_{WST} = \frac{H_{Load} * A_t}{C_{BOD}} = \frac{0.045 \frac{Kg_{BOD}}{m^2 * d} * 5.70 m^2}{0.5 \frac{Kg_{BOD}}{m^3}} = 0.51 \frac{m^3}{d} = 21.25 \frac{l}{h} \quad (4)$$

$$F_{realWST} = F_{WST} * \eta_{Dis} = 21.25 \frac{l}{h} * 0.5 = 10.6 \frac{l}{h} \quad (5)$$

$F_{WST} = \text{WST flow} = \frac{m^3}{d}$

$C_{BOD} = \text{Initial concentration} = \frac{Kg_{BOD}}{m^3}$

$H_{Load} = \text{Hydraulic load} = \frac{Kg_{BOD}}{m^2 * d}$

$\eta_{Dis} = \text{Efficiency distribution system} = 0.5$

It was necessary to add a factor for distribution efficiency, because it appeared that, approximately half of the branches were wet.

Finally the WST system was working with value close to 10 l/h, exactly 6 l/h (Because at 10 l/h peristaltic pump wears silicon hose) and 3 l/h for the smallest value.

3.2.2 Ebb-flow system

In Ebb-flow system the calculations for the flow is calculated with an estimated retention time of (0.25 h). Volume used for the Ebb-flow vessel was 60 litres.

$$F_{EF} = \frac{V_{us}}{H} = \frac{60l}{0.25h} = 240\frac{l}{h} \quad (6)$$

V_{us} = useful volume of the tank=60 l

H= Hydraulic residence time=0.25 h

Useful volume is calculated experimentally, so the system is going to work at 240 l/h for highest value and 120 l/h for the smallest one.

There are two holes (20*20 cm) in the EF system, one at the flow outside and the other one for the siphon. Ebb-flow holes without branches are shown with red squares in Picture 6.

PICTURE 6.Ebb-flow holes without branches show with red squares, TAMK greenhouse. (Photo: Alberto Freire, 2011)

$$A_b = 2*\pi*r^2 + 2*\pi*r*h \quad (7)$$

$$A_b = \text{Area of one branch} = 94.25\ cm^2 = 0.00942\ m^2$$

$$r = \text{Average radius of one branch} = 0.5\text{cm}$$

$$h = \text{Average high of branches} = 29.5\ \text{cm}$$

$$A_t = A_b * \frac{W_{\tan k} * L_{\tan k}}{(D_b)^2} = 94.25cm^2 * \frac{(56cm*75cm-(2*20cm*20cm))}{(1cm)^2} = 320450\ cm^2 \cong 32.04m^2 \quad (8)$$

$$A_{rt} = A_t * \eta = 32.04m^2 * 0.46 = 14.7\ m^2 \quad (9)$$

$$\eta_{EF} = \text{Efficiency of the surface EF}=0.46$$

For the EF system, the branches are better distributed than WST, so the efficiency of the surface is higher. In this case the water is covering entire available surface. Yield of the distribution system is 1. Ebb-flow setup is shown in Picture 7.

PICTURE 7. Ebb-flow setup, TAMK greenhouse. (Photo: Alberto Freire, 2011)

3.2.3 Synthetic leachate

This kind of synthetic leachate used in the project is produced, as close as possible to the water from Pälkäne (Ruokola), 400 mg BOD/l and known cellular composition of aerobic bacteria. In Table 3 aerobic bacteria element composition is shown. (Seabloom, R.W. et al., 2005)

TABLE 3. Aerobic bacteria element composition.

Element	Proportion
C	61.98
N	5.43
P	1

Synthetic leachate with bacteria composition, for the first four experiments is shown in table 4.

TABLE 4. Water for bacteria composition.

Compound	Concentration (mg/l)
BOD	400
NH_4^+	40
$P0_4^-$	4

For the realization of synthetic leachate glucose is used as carbon source , urea is used for source of nitrogen and in the case of phosphorus supply a commercial product called Bio Bact®. Bio Bact® has phosphorus in its composition, as well as other micronutrients necessary for the development of the metabolic functions of microorganisms, such as sulphur and zinc. To achieve an increase in phosphorus values, phosphate salts are added.

This synthetic leachate is used equally for both systems in order to compare the systems in the same conditions. The compounds used for water production are shown in Table 5 and Bio Bact® mass fraction in Table 6:

TABLE 5. Purity and mass fraction for different compounds.

Formula of compounds		Mass fraction (%)		Purity (%)
Glucose	$C_6H_{12}O_6$	40	C	100.0
Urea	$CO(NH_2)_2$	47	N	99.5
Sodium pyrophosphate	$Na_2HPO_4^-$	22	P	99.0

TABLE 6. Bio Bact® mass fraction different compounds.

	Mass fraction (%)	
Bio Bact®	0.60	NO_3^-
	2.10	NH_4^+
	0.50	P_{total}
	2.50	S
	0.02	Zn

Storage tank is always filled up with 900 l of potable water (90% of the tank), and the following proportions of each compound were added for the first four experiment. Experiments conditions are shown in Table 10 and 11.

TABLE 7.Compounds adding in experiments (1-4), high influent concentration.

Compounds	Mass (g)
Glucose	900.0
Urea	42.9
Bio Bact®	1161.7

In Picture 8 are shown compounds for the production of synthetic leachate.

PICTURE 8. Compounds for the production of synthetic water.

(Photo: Alberto Freire, 2011)

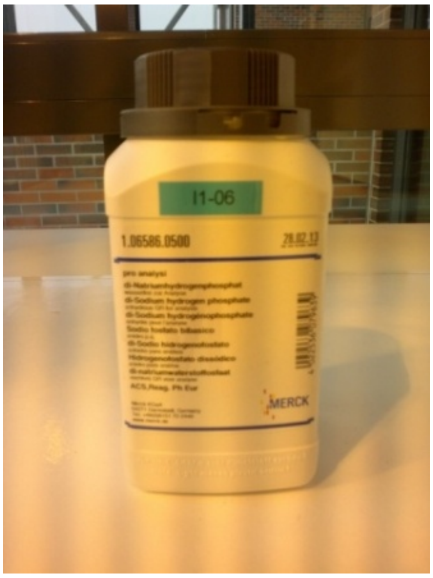
For the fifth and sixth experiment the phosphorus content was increased by adding sodium pyrophosphate. The amounts of each compound are mentioned in Table 8.

TABLE 8.Compounds adding in experiments (5-6), high leachate concentration.

Compounds	Mass (g)
Glucose	900.0
Urea	42.9
Biobact	1161.7
Sodium pyrophosphate	40.0

In two last experiments, the values of the synthetic leachate are quite similar to the leachate water from Pälkäne (Ruokola). Leachate with Pälkäne (Ruokola) composition is mentioned in Table 3.

To achieve higher concentration of total phosphorus, Sodium pyrophosphate was added is adding; it needs to be preheated before adding, because the solubility of the compound is quite poor at 20ºC. Sodium pyrophosphate (TP) for the production of synthetic leachate is shown in Picture 9.



PICTURE 9. Sodium pyrophosphate (TP) for the production of synthetic leachate. (Photo: Alberto Freire, 2011)

3.3. Alternatives for process setup

This project initially consisted only of the WST system. But the idea of obtaining a completely new system for leachate treatment, rise up the Ebb-flow system design.

3.3.1 Configuration of the process

Originally the Ebb-flow system works in batch in order to keep constant parameters in leachate influent, and leachate water is removed after it has been. But the water consumption will be really high so made it not viable. Final decision was continuous system with a recirculation storage tank (Picture 11), to keep the bacteria alive.

PICTURE 10. Initial equipment one vessel. (Photo: Alberto, 2011)

PICTURE 11. Initial equipment structure. (Photo: Alberto, 2011)

In order to get constant parameters another tank was added to the system, Picture 12. This tank (2) is used as a storage tank and discharged into the tank (1). The purpose was to obtain a batch system with constant parameters, at the moment to realize the test.

PICTURE 12. Testing configuration. (Photo: Alberto Freire, 2011)

The initial idea for the distribution and flow control system in Willow stack tower was to have a drip system, but the flow was too small to achieve a homogeneous distribution over the willow branches. It is decided spray system, which is more simple and efficient than the drip system. One peristaltic pump is responsible of flow control. WST system flow distribution is shown in Picture 13.

PICTURE 13. WST system, flow distribution construction.
(Photo: Alberto Freire, 2011)

3.3.2 Ebb-flow

The former idea for the EF distribution system was having a pipeline system along with tiny holes. For EF, the difficulty to control the flow and the idea to obtain water to cover as much biofilter surface as possible, modified this initial idea of Ebb-flow distribution system. Final decision was to choose a dual output system, which controls the flow through two ball valves. One of the outputs are directed to the the biofilter and the other is directed to the tank, to get a good homogenization of the contents of the storage tank. In this case the impulsion system is a centrifugal pump. EF, flow control system is shown in Picture 14.

PICTURE 14. EF, flow control system. (Photo: Alberto Freire, 2011)

3.3.3 Ebb-flow siphoning system

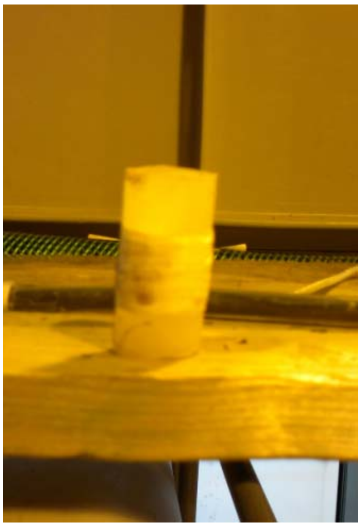
The siphoning system was modified several times; the initial internal pipe, available initial drainage (ø=1.75 cm), but the outflow was not fast enough; so it was changed by another one of bigger dimensions (ø=2.50 cm).

As an added security system is a snorkel. It is a tube that ensures the siphon is able to "breathe" (release the pressure difference) and stop operation of the siphon. This snorkel is adjustable in height, thus controlling the height of the siphon stop. The siphoning system and snorkel are shown in Pictures 15 and 16.

PICTURE 15. Siphoning system.
(Photo: Alberto Freire, 2011)

PICTURE 16. Siphon system, snorkel.
(Photo: Alberto Freire, 2011)

To modify the height of the siphon discharge, then added a small pipe extension, getting greater use of the surface of the branches. In order to get proper siphon discharges at low flow rates a smaller diameter pipe was added in the bottom of the discharge pipe. With this change the siphon is able to cause big enough pressure change to start the discharge. The smaller diameter pipe can be seen in the Picture 17:



PICTURE 17. Smaller diameter pipe, siphon starts work at low flows.
(Photo: Alberto Freire, 2011)

The initial idea to measure the flow rate was to insert flow meters. Treated water was very dirty to use this system. For this reason the flow rate was measured regularly with the help of bucket-stopwatch combination. This method involves timing to fill the bucket. The bucket-stopwatch method can be seen in the Picture 18.

PICTURE 18. Bucket-stopwatch method. (Photo: Alberto Freire, 2011)

3.3.4 Bacteria inoculums

Inoculums for growing bacteria in greenhouse experiments have been obtained from the WST plant from Pälkäne (Ruokola). Some of this Pälkane branches were cut and introducing into the systems. Bacteria were fed regularly to keep them alive and to improve their growth. Inoculum from Pälkäne be seen in the Picture 20 and how EF system is inoculated in Picture 19.

PICTURE 19. EF inoculation from Pälkäne (Ruokola). (Photo: Alberto Freire, 2011)

PICTURE 20. Pälkäne (Ruokola) WST inoculums.(Photo: Alberto Freire, 2011)

4. SYSTEM DESCRIPTION

4.1. Block diagram

The block diagram of experiment set up can be seen in Figure 7.

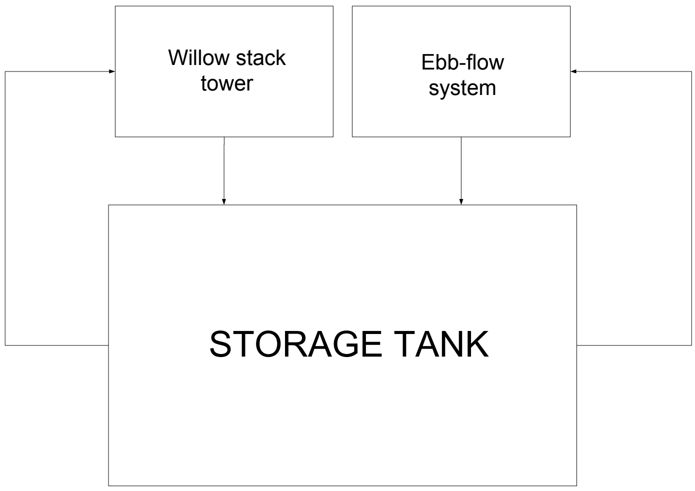


FIGURE 7. Block diagram of the process

4.2. Mass balance

The mass balance of the system can be seen in Figure 8.

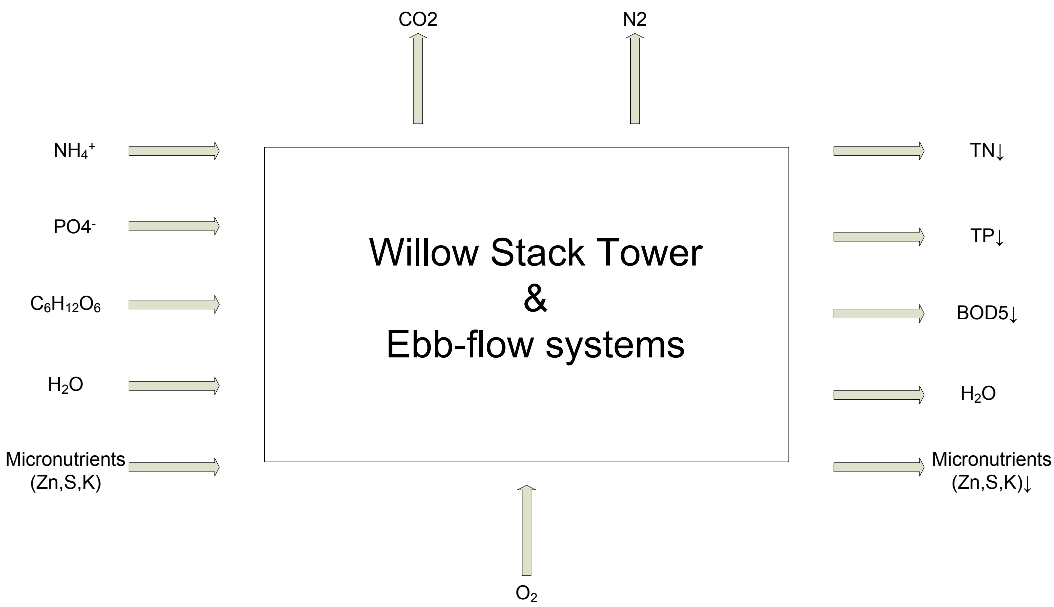


FIGURE 8. Mass balance diagram of the process.

4.3. Flow diagram

Two different flow diagrams experiment configuration set up can be seen in Figure 9 testing configuration and maintenance configuration in Figure 10.

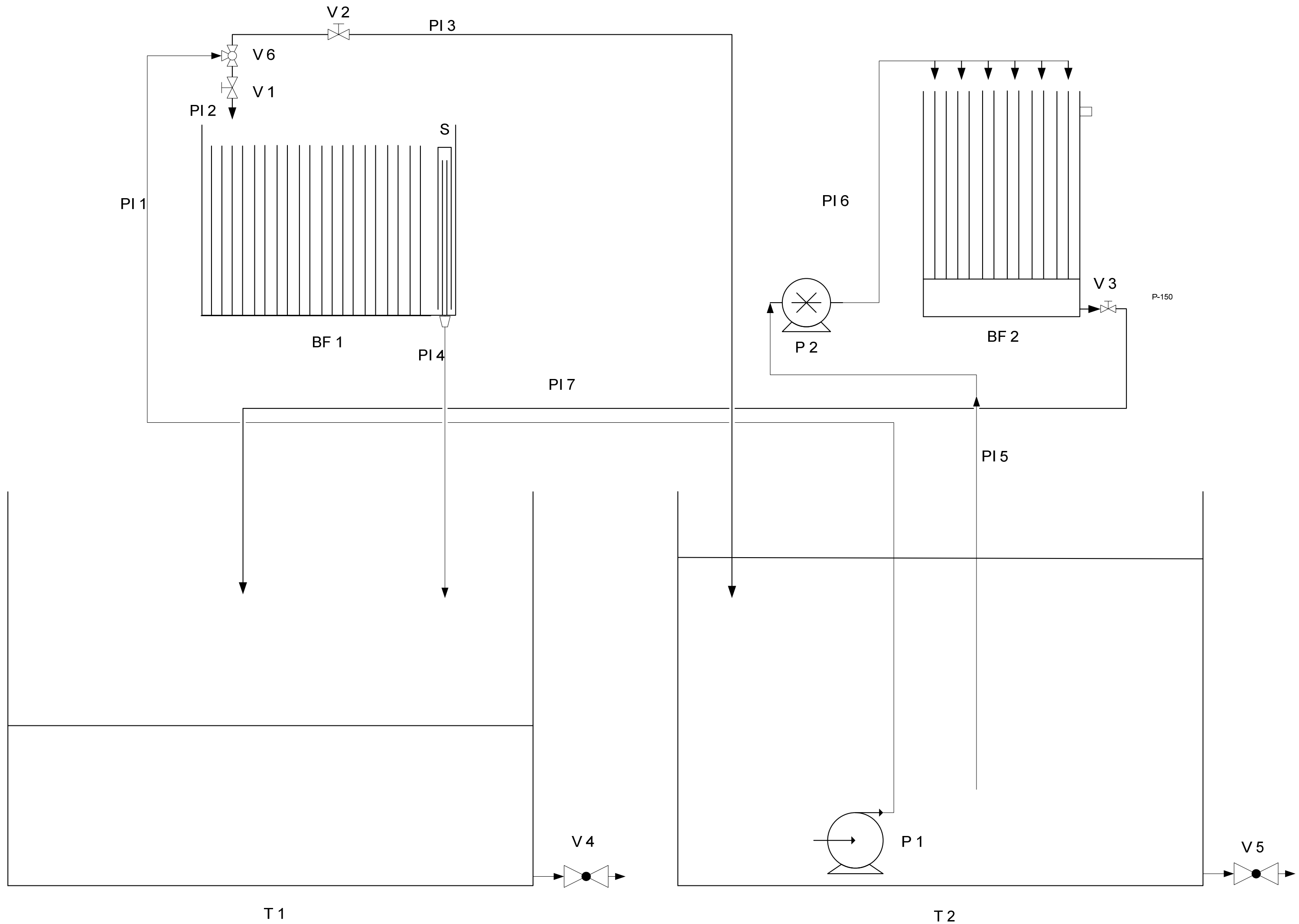


FIGURE 9. Testing configuration.

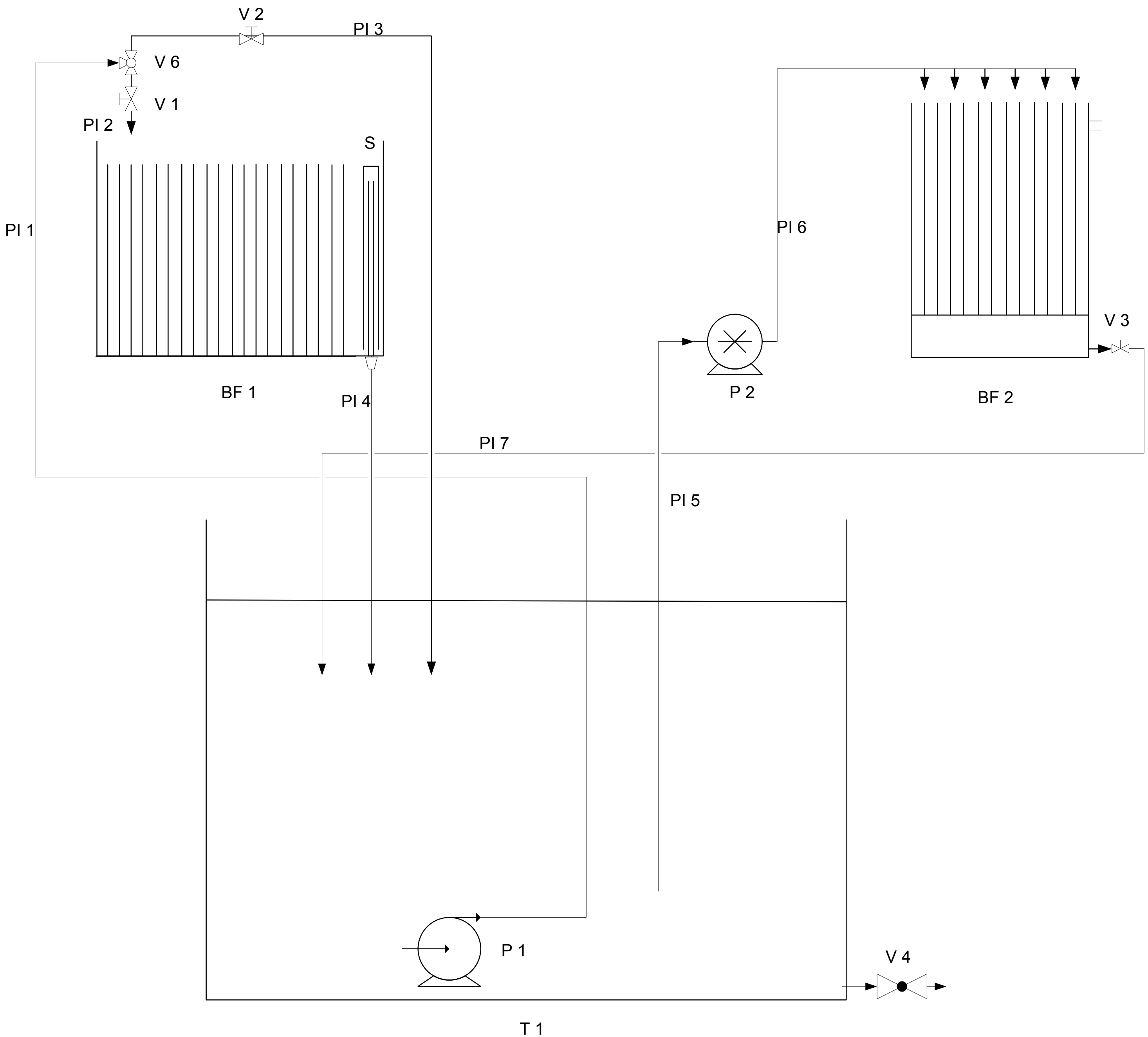


FIGURE 10. Maintenance configuration to keep the bacteria alive.

Nomenclature of flow diagrams is shown with next abbreviations.

BF	Biofilter	P	Pump
Number	Equipment identification	PI	Pipe
S	Siphon	V	Valve
T	Storage tank		

4.4. List and detail description of equipments (Size and characteristic)

In this part of the project all the equipment size, material composition and characteristic are shown.

BF1: Plastic tank for EF system.

Dimensions: 80X40X60cm ($L \times H \times W$), Length*High*Wide.

BF 2: Methacrylate tank for WST system.

Dimensions: 50X70X30cm ($L \times H \times W$).

T1 and T2: Plastic corrosion resistant, for storage wastewater (1000 l).

Dimensions: 110X96X91cm ($L \times H \times W$).

The Principal system equipment can be seen in Picture 21.

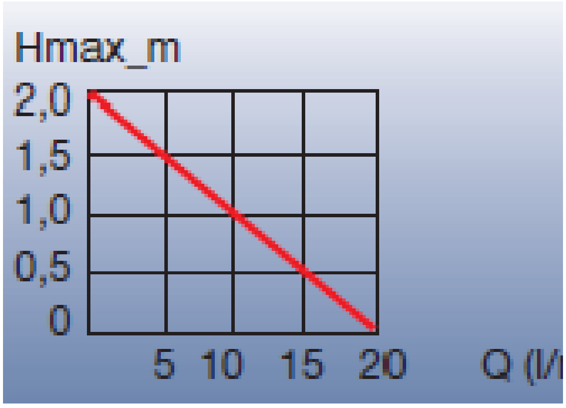
PICTURE 21. Principal system equipment.(Photo: Alberto Freire, 2011)

P1: Centrifugal pump, “Eheim 1250”.

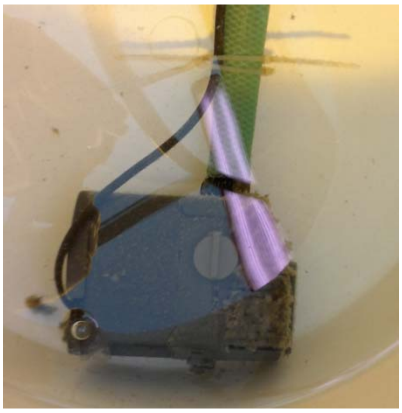
Max. Output 1200 l/h. Max. Delivery head H_{max} 2.0 m.

Dimensions: 17.8X9.6cmX12.1cm ($L \times H \times W$).

The P1 diagram High max Vs Flow can be seen in Figure 22 and P1 centrifugal pump can be seen in figure 23.



PICTURE 22.P1 diagram H Vs F.
(http://www.mondside.com, 2011)



PICTURE 23. P1 Centrifugal pump.
(Photo: Alberto Freire, 2011)

P2: Peristaltic pump

Heidolph pump drive 5201. (http://www.heidolph-instruments.com)

Flow rates of 0.3 - 790 ml/min with single-channel pump heads.

Speed range from 5 - 120 rpm.

Peristaltic pump is shown in Picture 24.

PICTURE 24. Peristaltic pump (P 2). (Photo: Alberto Freire, 2011)

S : Siphon

The dimensions of the different components of the siphon used for the Ebb-flow system are shown below.

Principal pipe: ø=7.5cm, H=40cm.

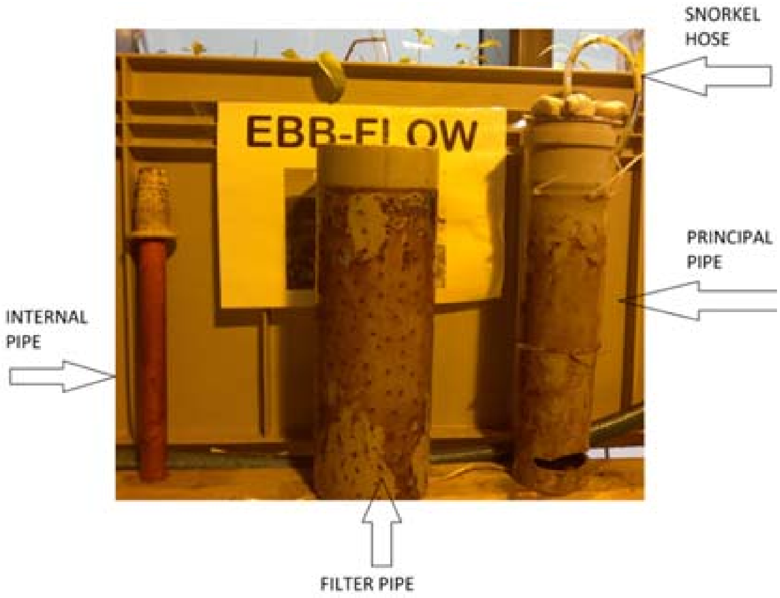
Filter pipe: ø=10.5cm, H=35cm.

Internal pipe: ø=2.5cm, H=29cm.

Snorkel hose: ø=7.5cm, H=40cm.

Reduction pipe: ø=0.8cm

Siphon different parts can be seen in Picture 25.



PICTURE 25. Siphon different parts. (Photo: Alberto Freire, 2011)

V1 and V2: Globe valves, ABS material, ø=0.8cm.

V3: Globe valve, stainless steel material, ø=0.8cm.

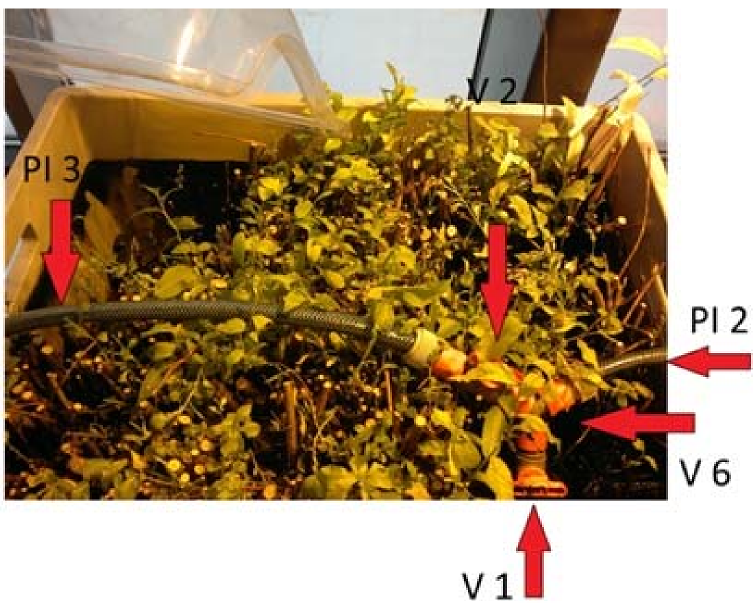
V4 and V5: Globe valves, ABS material, ø=3.5cm.

V6: Spilt, ABS material, ø=0.8cm.

PI1, PI2, PI3, PI4 and PI7: PVC hoses, ø=2.5cm.

PI5 and PI6: Silicon hoses, ø=0.8cm.

Different parts of the EF distribution system can be seen in Picture 26.



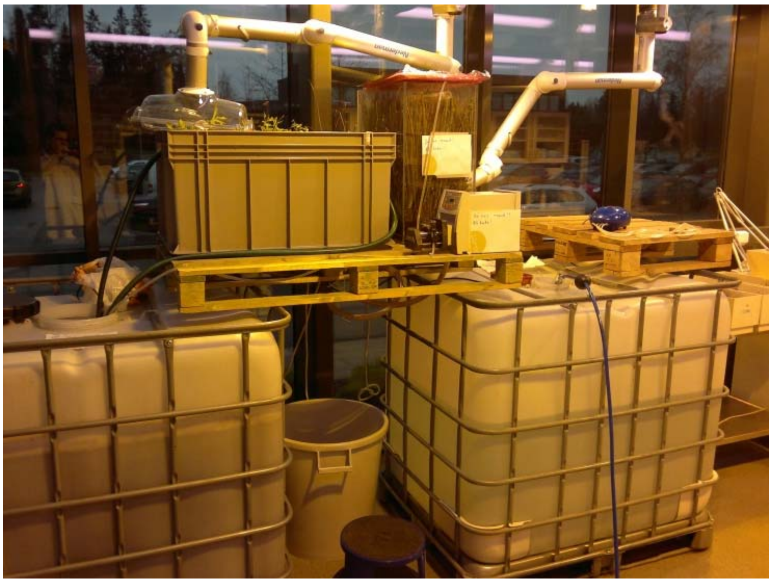
PICTURE 26. Different parts of EF distribution system. (Photo: Alberto Freire, 2011)

5. DESCRIPTIONS OF THE PROCESS AND SET UP

5.1. General description of the process

There are two different biofilter systems, responsible of reducing water contaminants from landfill leachate. And there are two configurations for the system work, maintenance configuration and testing configuration.

Maintenance configuration is a continuous system, where P 1 and P 2 obtain water from T 1, and after passing through the biofilters, water is deposited again in T 1 (figure 21). So this way it maintains the bacteria alive in the filtering system. Maintenance configuration can be seen in Picture 27:



PICTURE 27. Maintenance configuration. (Photo: Alberto Freire, 2011)

Testing configuration, Picture 28, is a batch configuration where the parameters are maintained constant. P1 and P2 obtain water from T2, and after pass through biofilters, water is discharge in T1. Initially this tank, T1, is empty and the other one is full of leachate water. Tests are implemented with this configuration. Testing configuration can be seen in Picture 28.

PICTURE 28. Testing configuration. (Photo: Alberto Freire, 2011)

The first system, BF 1, is the Ebb-flow system, responsible for cleaning the leachate water through the system that has provided sufficient oxygenation by Ebb-flow movement. This equipment is able to realize this movement with a siphon system. BF 1 obtained the water through a centrifugal pump, P 1. This water is storage in tank, T 1, during the bacteria feeding and is storage in tank, T 2 during the test. In order to control the flow, there is a system of two valves with split flow, V 6. The first valve, V 1, distributes the water over willow stacks and the second one, V 2, recirculates the water to the storage tank.

5.1.1 Siphon explanation

All the fluid flows from higher energy level to levels with lower energy. In the siphon the potential energy is transformed into kinetic energy. The operation principle of the siphon is perfectly explained in the book, “Introduction to fluid mechanics and fluid machines” (S. K. Som and G. Biswas, 2004, 190)

5.1.2 Spray system

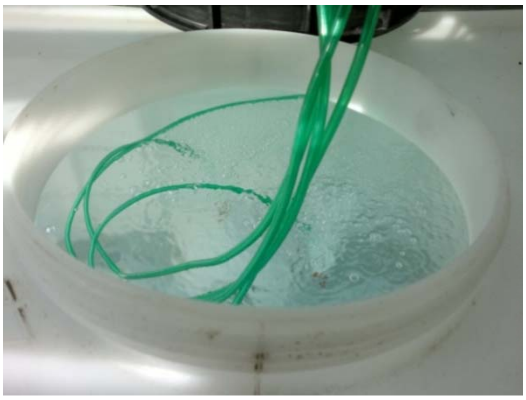
The WST system is the responsible of cleaning leachate water through the system that has provided sufficient oxygenation by a spray system. This spray system works with the pressure of a peristaltic pump, P 2. Pressurized water is distributed with a silicon pipe, PI 6, with small holes and close at the end; this pipe is placed on the top of the WST system. WST pilot plant spray system is shown in Figure 29.

PICTURE 29. WST spray system. (Photo: Alberto Freire, 2011)

5.2. Set up of experiments

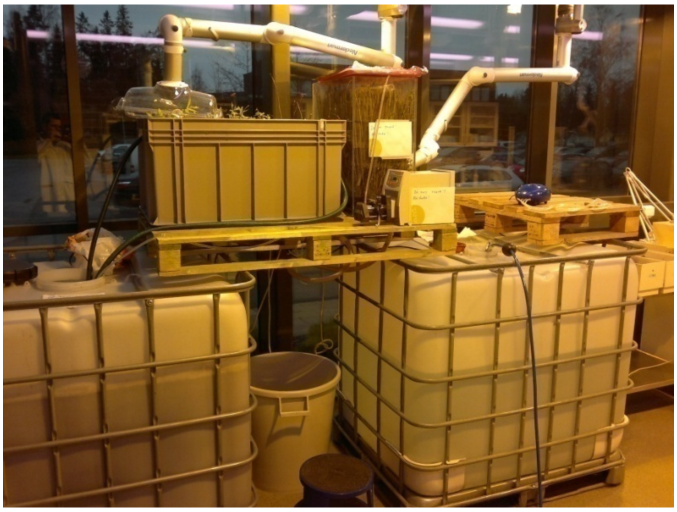
The day before the test will be started, the test tank needs to be filled with potable water which is aerated by the operation of a compressor, Picture 30; with this previous process, the chloride in the water is removed, fresh water aeration is shown in Picture 31.

PICTURE 30. Compressor. (Photo: Alberto Freire, 2011)



PICTURE 31. Fresh water aeration. (Photo: Alberto Freire, 2011)

During the testing day, the system will be started with maintenance configuration, picture 32.



PICTURE 32. Maintenance configuration. (Photo: Alberto Freire, 2011)

The first step is empty tank (T1), open carefully valve (V4). At the same time all the compounds needed to produce synthetic leachate are added into the tank (T2). To obtain homogenous leachate, water is mixed with the centrifugal pump (P1) and the aeration is removed. Used leachate with poor nutrients concentration is removed in order to get new leachate inside, Picture 33.

PICTURE 33. Removing the used leachate from the tank. (Photo: Alberto Freire, 2011)

Simultaneously, the configuration of the system is changed in the testing configuration, picture 34.

PICTURE 34. Testing configuration. (Photo: Alberto Freire, 2011)

When testing time starts, the values of time and date are registered in a data bank; while flow is measured by bucket-stopwatch method.

Whereas the process goes on, the sample flasks are readied to preserve the sample. There are four replicas from both systems (WST and EF) and the initial value during all the process. For each replica, 3 samples are taken, the first one to analyze DOB_5, the second to analyze TN and TP and the last is used as spare. Total of 36 sample flasks are preserved in a fridge, at 4 ºC.

The pH and temperature are analyzed from all the replicates, before be introduced in the fridge. Values are registered in a data bank during the test. When testing time has finished the system returns to maintenance configuration and tank (T 2) is cleaned.

5.3. Analyzing methods

During this project the following parameters were analyzed with this different analytical equipment in TAMK laboratories.

5.3.1 Temperature and pH

These parameters are measured, just after sampling. This way none of the parameters is modified because of storage time. These parameters have been analyzed with Mettler Toledo pHmeter, it is shown in Picture 35.

PICTURE 35. Mettler Toledo, pHmeter. (Photo: Alberto Freire, 2011)

5.3.2 Total phosphorus

Total phosphorus has been analyzed with HACH DR 2800 Spectrophotometer. Samples are wet digested with sulphuric acid. Spectrophotometer is used to analyze the samples, Picture 36.

PICTURE 36. HACH DR 2800 Spectrophotometer. (Photo: Alberto Freire, 2011)

Complete instructions in: Instructions book, HACH Lange method. Method 8190. Phosphorus, total, digestion.

5.3.3 Biochemical oxygen demand during five days

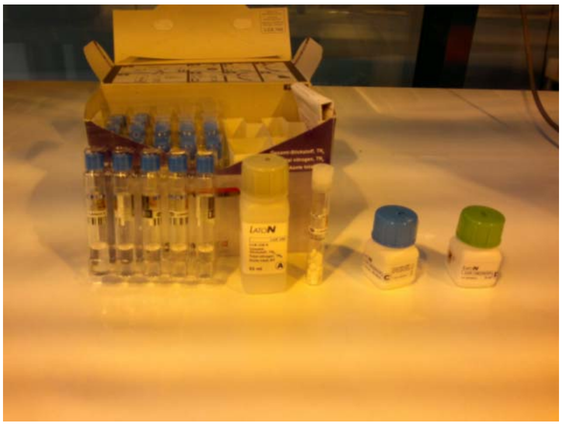
BOO_5 determinations of the undiluted sample are analyzed with the OxiTop® Control and the OxiTop® measuring system. BOD_5 analyzing equipment is shown in Picture 37.

PICTURE 37. BOD_5 analyzing equipment. (Photo: Alberto Freire, 2011)

Complete instructions in: Operating manual. System OxiTop® OC100 controller. WTW, 2006.

5.3.4 Total nitrogen

For the determination of TN a new method is applied, "LANGE LCK 283", this method is faster and easier than traditional Kjeldahl method, which takes two days for digestion, distillation and titration. TN kit "LANGE LCK 283" can be seen in Figure 38.



PICTURE 38. TN kit, "LANGE LCK 283". (Photo: Alberto Freire, 2011)

Complete instructions in: Instructions guide, HACH Lange method. LCK 238. Total Nitrogen.

6. RESULTS

This thesis present the process and the results and conclusions of experimental set up of a willow stack tower model used for waste water or leachate treatment purposes during the experiments done during September 2011-January 2012 in TAMK laboratories. Initial values for the experiments are summarized in table 9.

TABLE 9. Initial experimental values before the treatment.

	Name	Temperature	Desviation	pH	Desviation	BOD5 (mg/l)	Desviation	TN (mg/l)	Desviation	PO4- (mg/l)	Desviation
Experiment 1	Initial	17,1	0,49	7,3	0,0	447,5	12,0	35,2	0,6	0,7	0,5
Experiment 2	Initial	17,1	0,14	6,7	0,1	132,0	19,80	29,6	0,7	0,1	0,0
Experiment 3	Initial	18,6	0,2	6,9	0,0	384,3	41,3	28,5	1,1	0,6	0,3
Experiment 4	Initial	18,5	0,2	6,8	0,0	145,3	11,5	21,1	1,1	0,1	0,0
Experiment 5	Initial	17,8	0,7	7,2	0,0	542,3	32,7	29,3	1,9	12,8	2,5
Experiment 6	Initial	19,0	0,3	5,4	0,0	66,2	20,3	14,3	1,2	6,8	2,2

In this part values are compared the initial value for both system:

EF: Ebb-flow system.

WST: Willow Stack Tower.

The flow rate for the different system and experiments are shown in table 10.

TABLE 10. Flow at different experiments and systems.

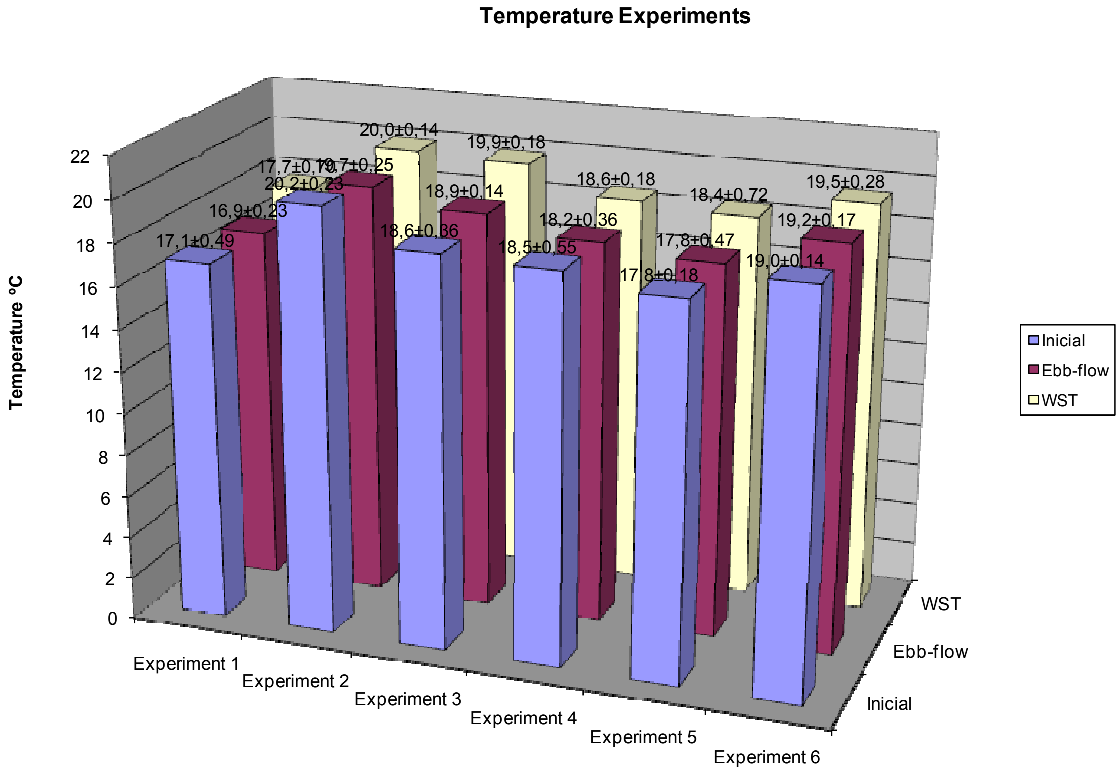
	System	Flow (l/h)
Experiment 1	Ebb-flow	127,0
	WST	5,9
Experiment 2	Ebb-flow	250,0
	WST	3,0
Experiment 3	Ebb-flow	253,1
	WST	3,0
Experiment 4	Ebb-flow	126,0
	WST	6,0
Experiment 5	Ebb-flow	261,0
	WST	3,0
Experiment 6	Ebb-flow	137,0
	WST	6,0

The final values after the treatment in different systems and experiments are shown in Table 11.

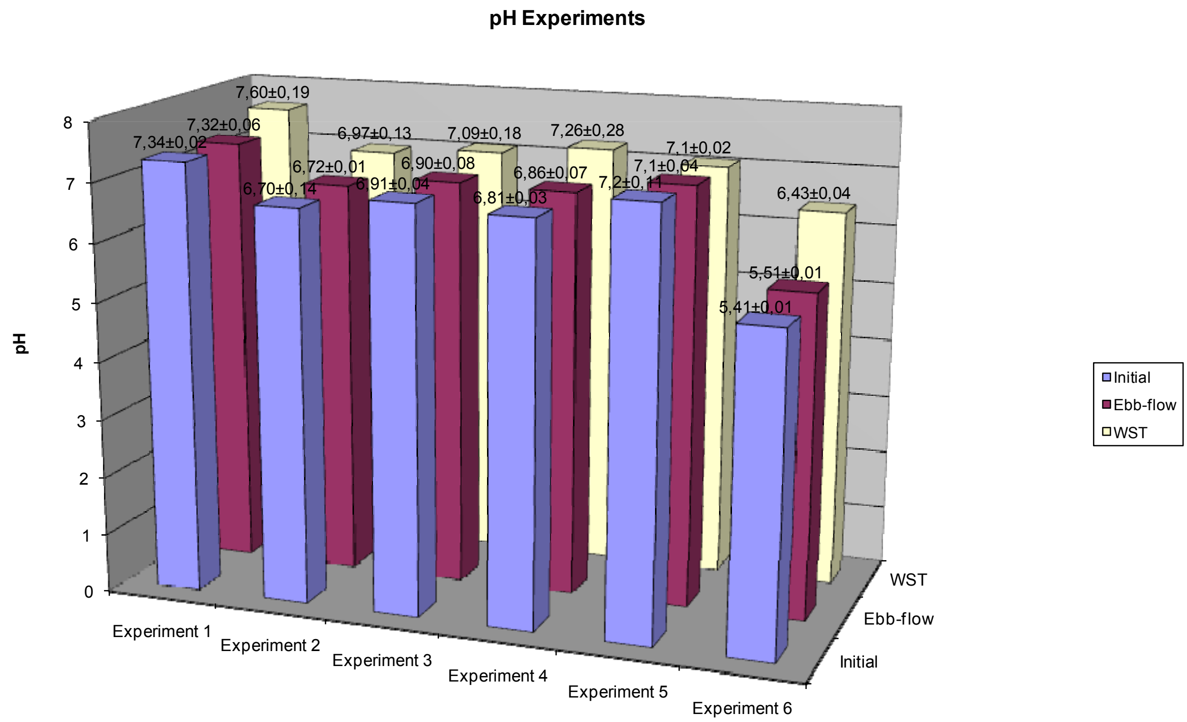
TABLE 11. Values after treatment for each experiment and system.

	System	Temperature	Desviation	pH	Desviation	BOD5 (mg/l)	Desviation	TN (mg/l)	Desviation	PO4- (mg/l)	Desviation
Experiment 1	Ebb-flow	17,0	0,2	7,3	0,1	379,3	6,4	33,1	1,4	0,4	0,4
	WST	17,7	0,7	7,6	0,2	250,5	154,2	33,5	0,9	0,1	0,2
Experiment 2	Ebb-flow	17,0	0,3	6,7	0,0	128,0	3,5	28,4	1,3	0,1	0,1
	WST	17,7	0,2	7,0	0,1	130,0	11,5	30,3	0,8	0,1	0,0
Experiment 3	Ebb-flow	18,9	0,1	6,9	0,1	350,5	25,6	20,9	1,5	0,6	0,1
	WST	19,9	0,4	7,1	0,2	186,0	96,2	19,9	0,3	0,2	0,1
Experiment 4	Ebb-flow	18,2	0,4	6,9	0,1	140,8	4,5	23,5	0,6	0,1	0,0
	WST	18,6	0,6	7,3	0,3	131,0	14,8	24,2	1,3	0,1	0,0
Experiment 5	Ebb-flow	17,8	0,5	7,1	0,0	526,5	35,1	19,0	3,4	8,8	7,5
	WST	18,4	0,2	7,1	0,1	421,3	23,4	16,1	1,5	7,4	4,3
Experiment 6	Ebb-flow	19,2	0,2	5,5	0,0	60,1	35,1	13,5	0,6	6,5	2,1
	WST	19,5	0,1	6,4	0,0	38,0	23,4	11,4	0,8	6,7	0,8

Temperature and pH values for all the experiments are shown in Picture 39 and 40.

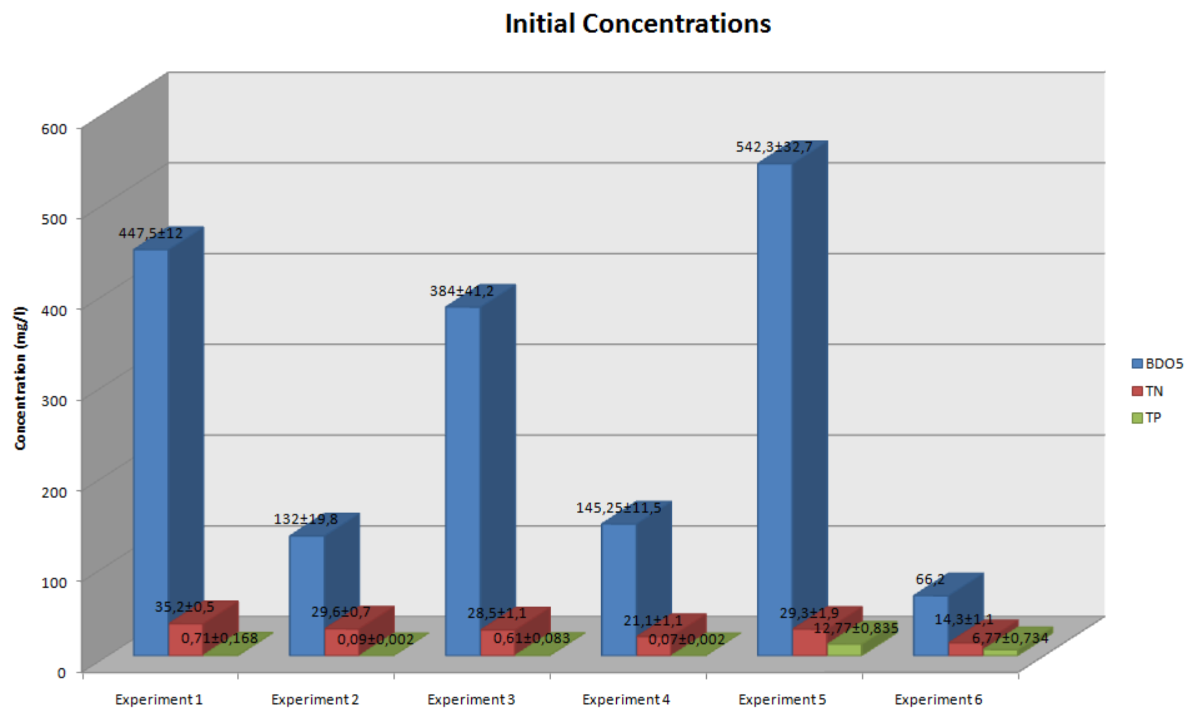


PICTURE 39. Temperature at different experiments and systems.



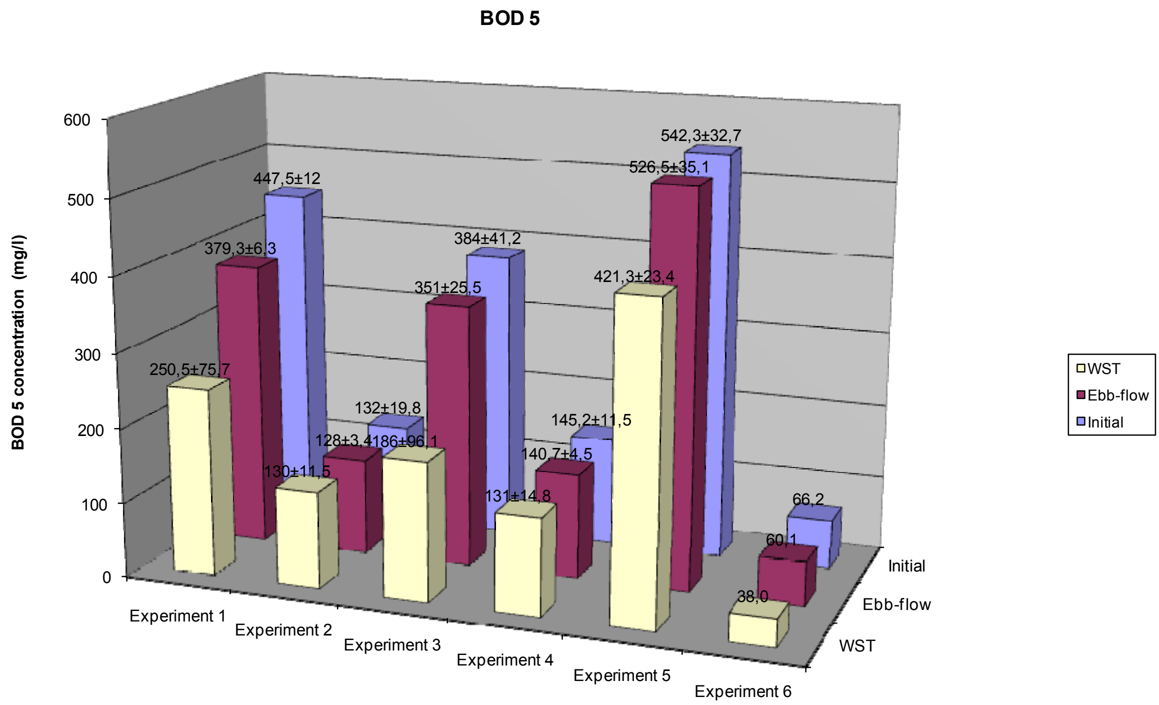
PICTURE 40. pH at different experiments and systems.

Values of the initial influent concentration for the different experiments are shown in Picture 41.

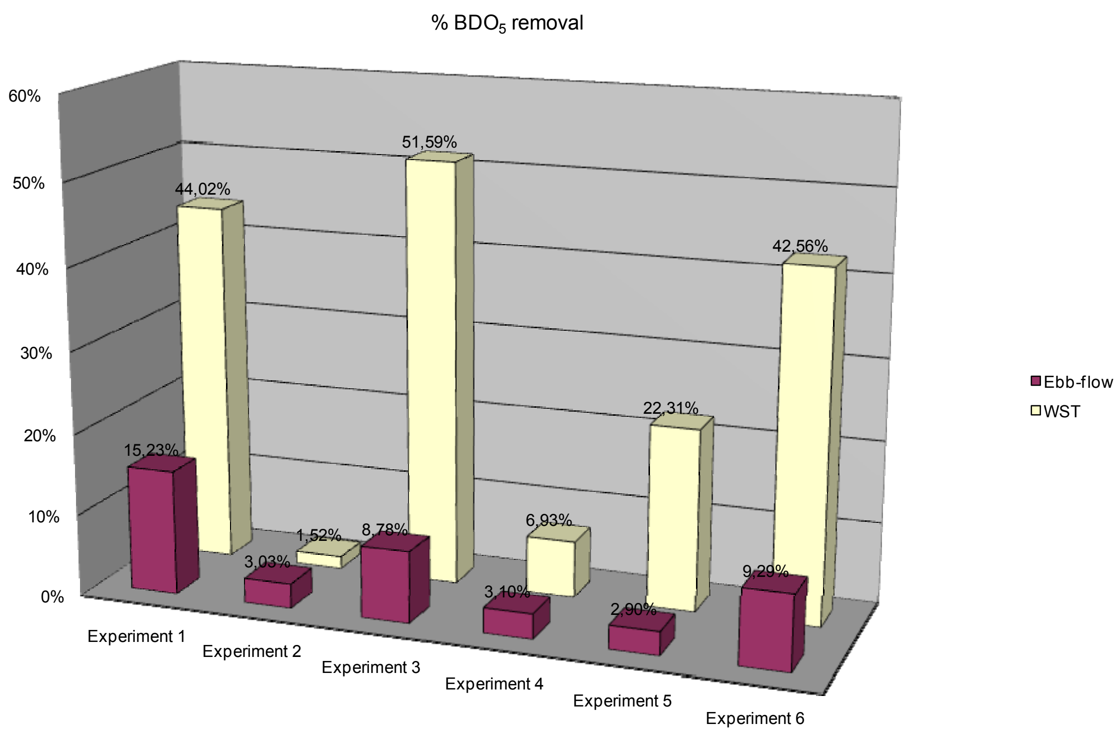


PICTURE 41. Initial concentration at different experiments.

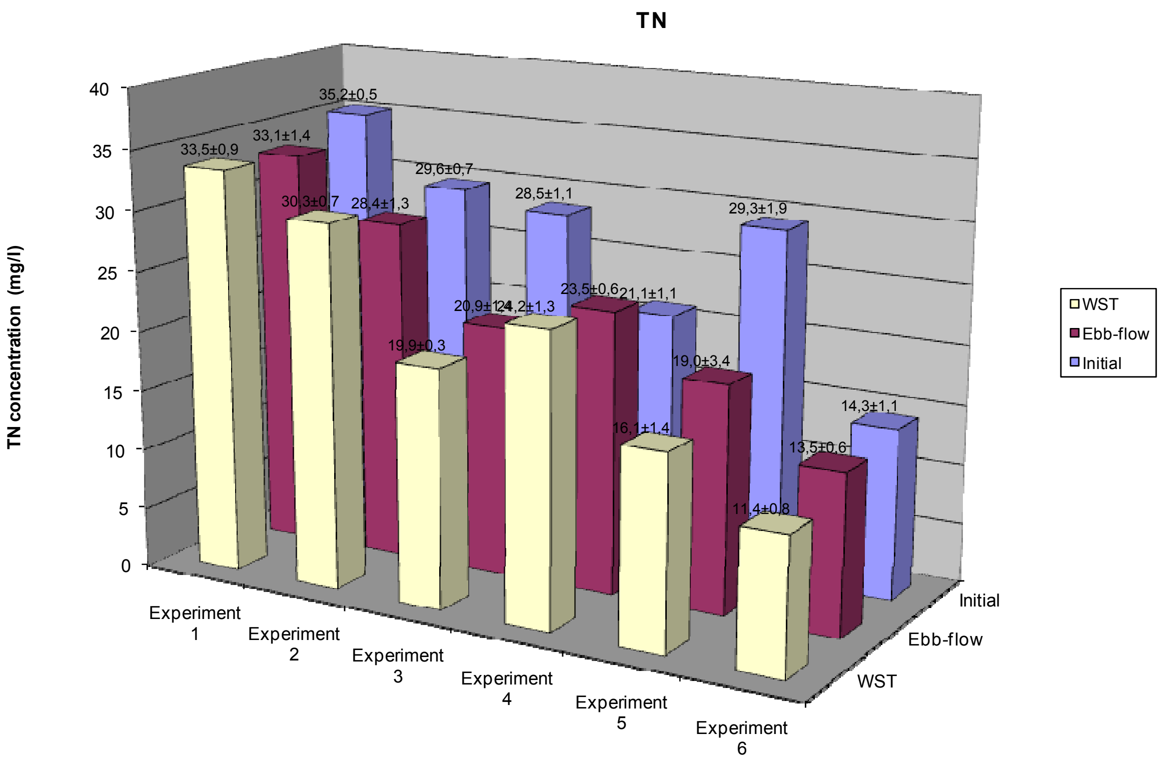
Removal percentage and direct values; per different chemical parameters, experiments and systems are shown in Pictures 42 - 47.



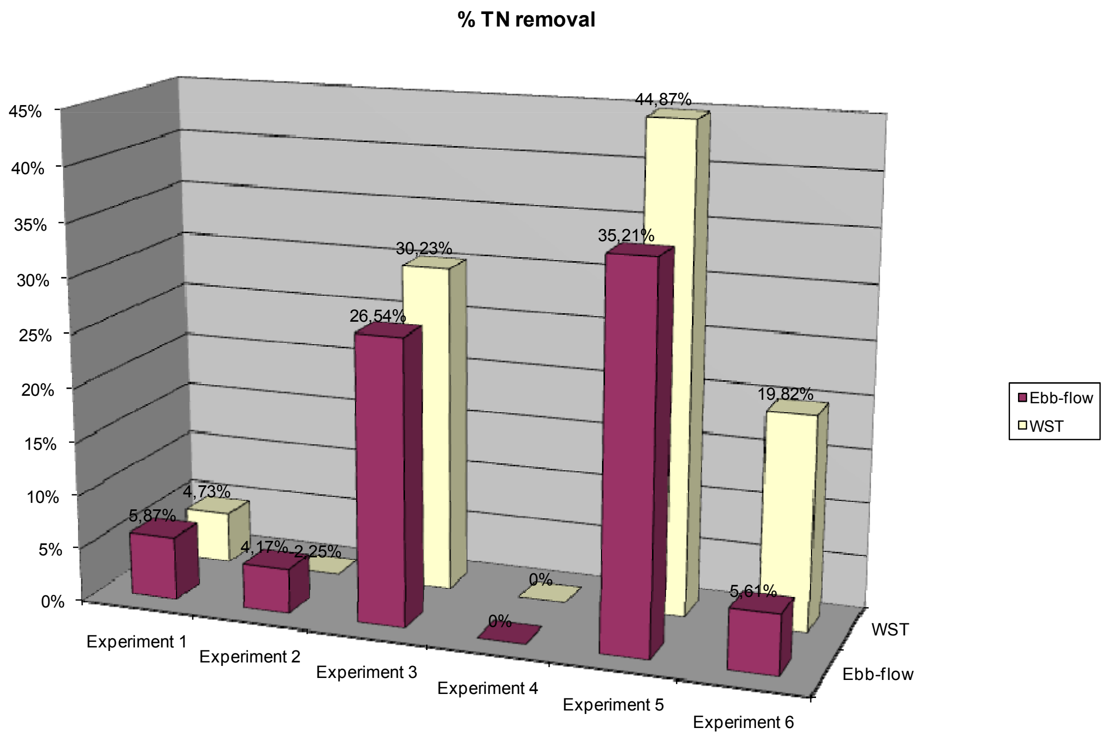
PICTURE 42. BOD_5 concentration at different experiments and systems.



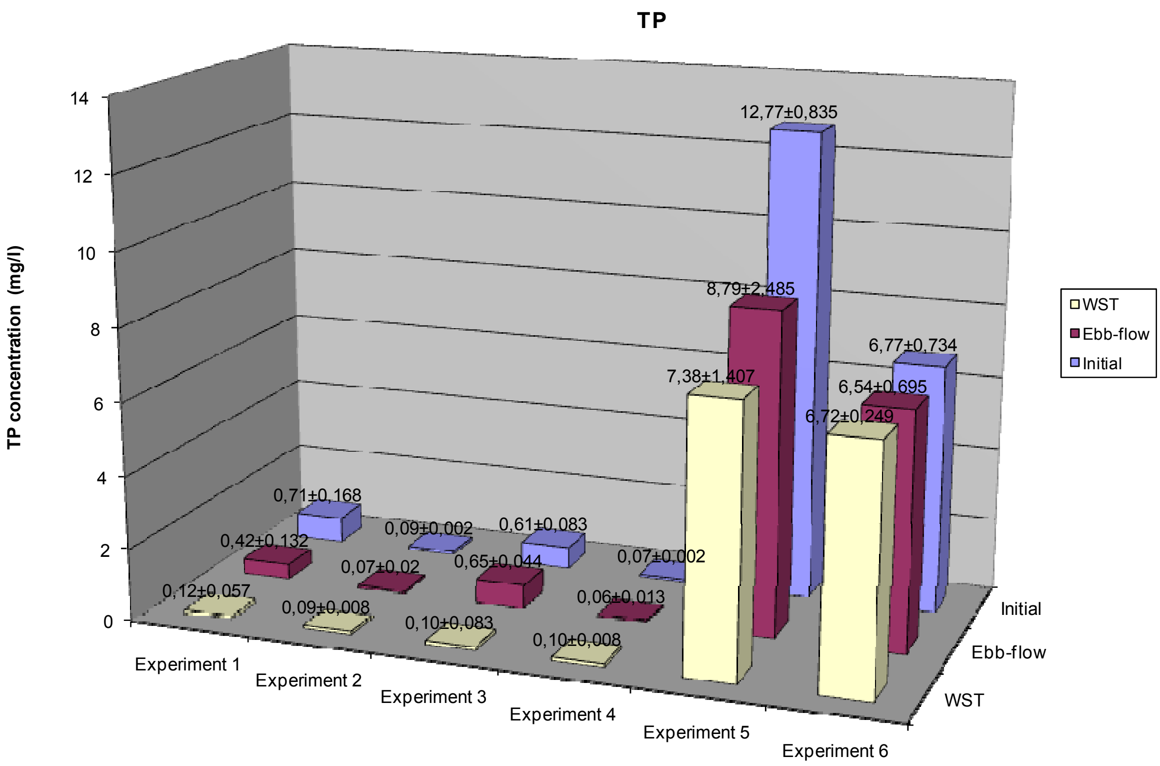
PICTURE 43. BOD_5 removal percentage at different experiments and systems.



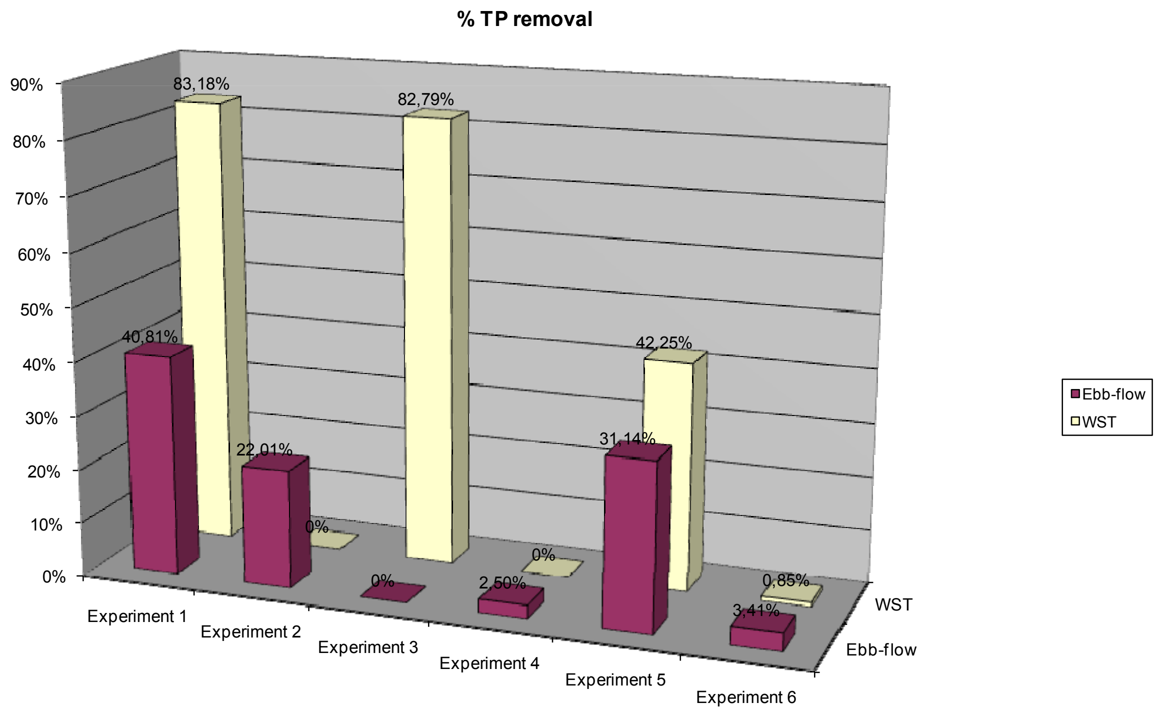
PICTURE 44. TN concentration at different experiments and systems.



PICTURE 45. TN removal percentage at different experiments and systems.



PICTURE 46. TP concentration at different experiments and systems.

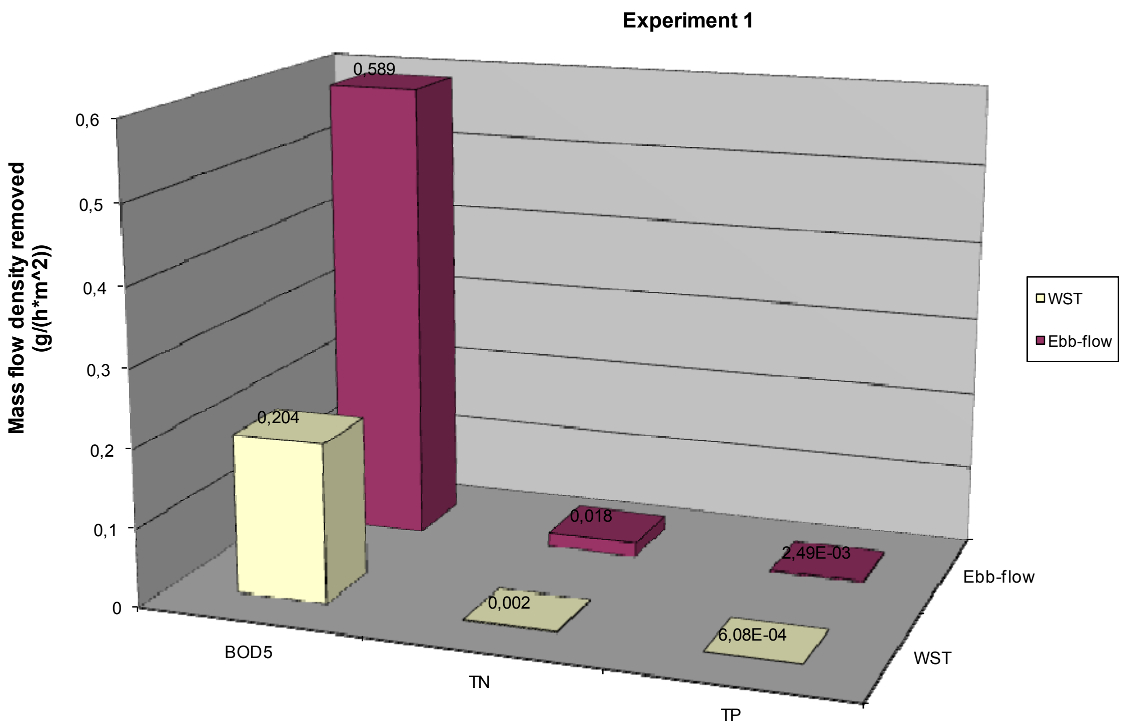


PICTURE 47. TP removal percentage at different experiments and systems.

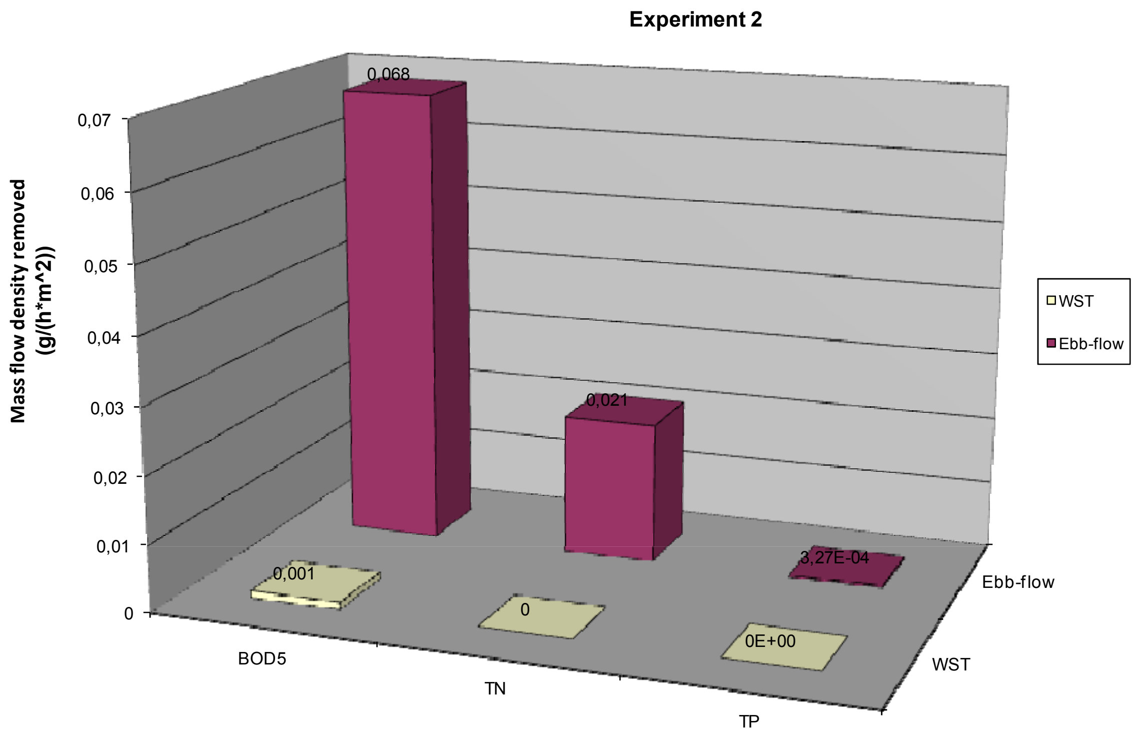
Removal percentage values need to be evaluated per concentration, flow and willow surface, because systems are working in different condition, and both systems have different willow surface area. For that reason parameters have to be studied with mass flow density removed (ϴ); it is calculated with equation 10.

$$\theta = \frac{Flow * removal\ concentration}{Surface} = \frac{\frac{l}{h} * \frac{mg\ \text{removed}}{l}}{m^2} * 1000 * \frac{mg}{g} = \frac{g\ \text{removed}}{m^2 * h} \quad (10)$$

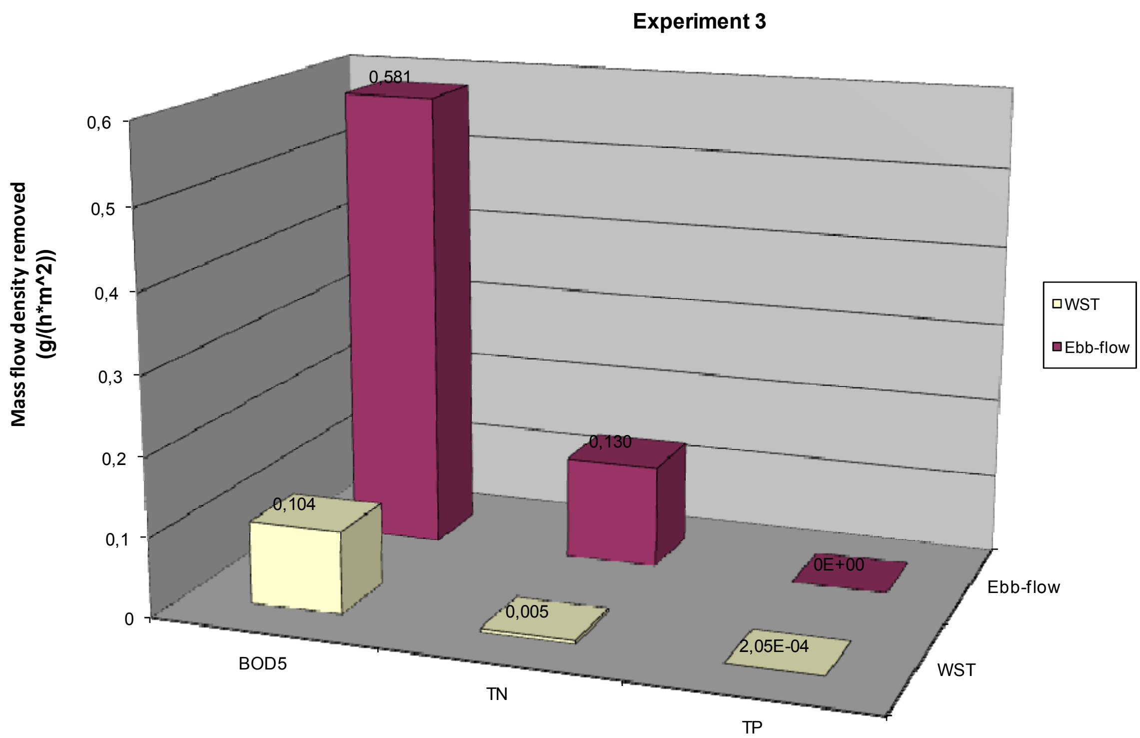
The values for all experiments are shown in Picture 48 to 53.



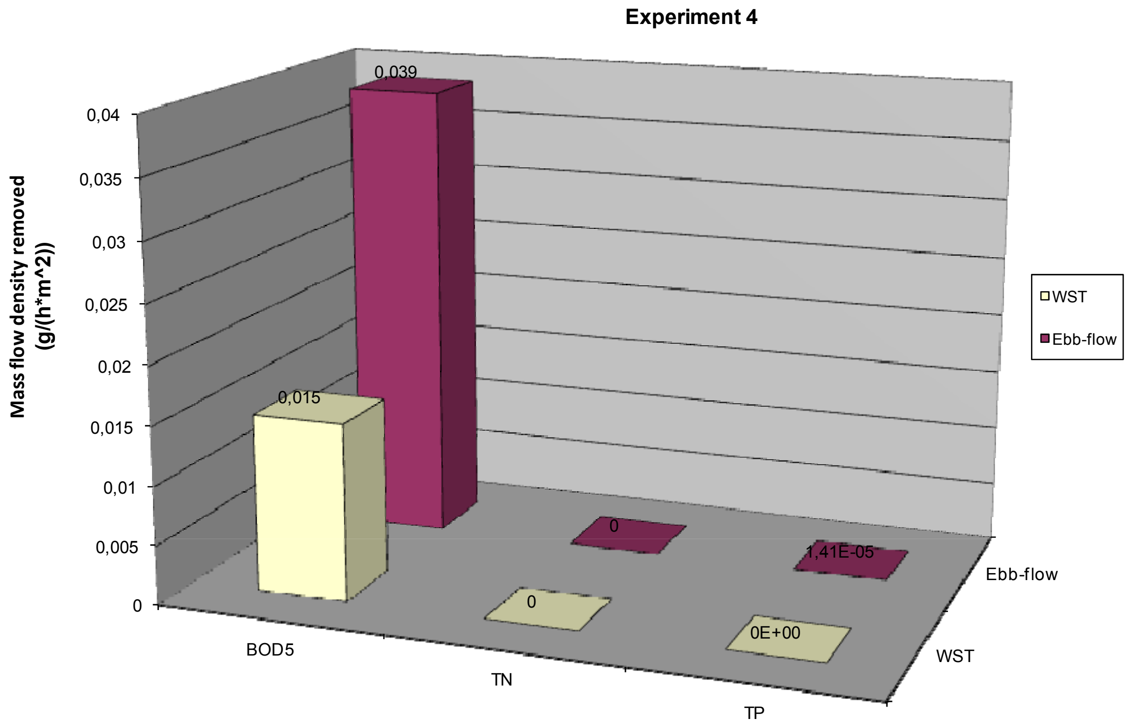
PICTURE 48. ϴ for different parameters and systems for experiment 1.



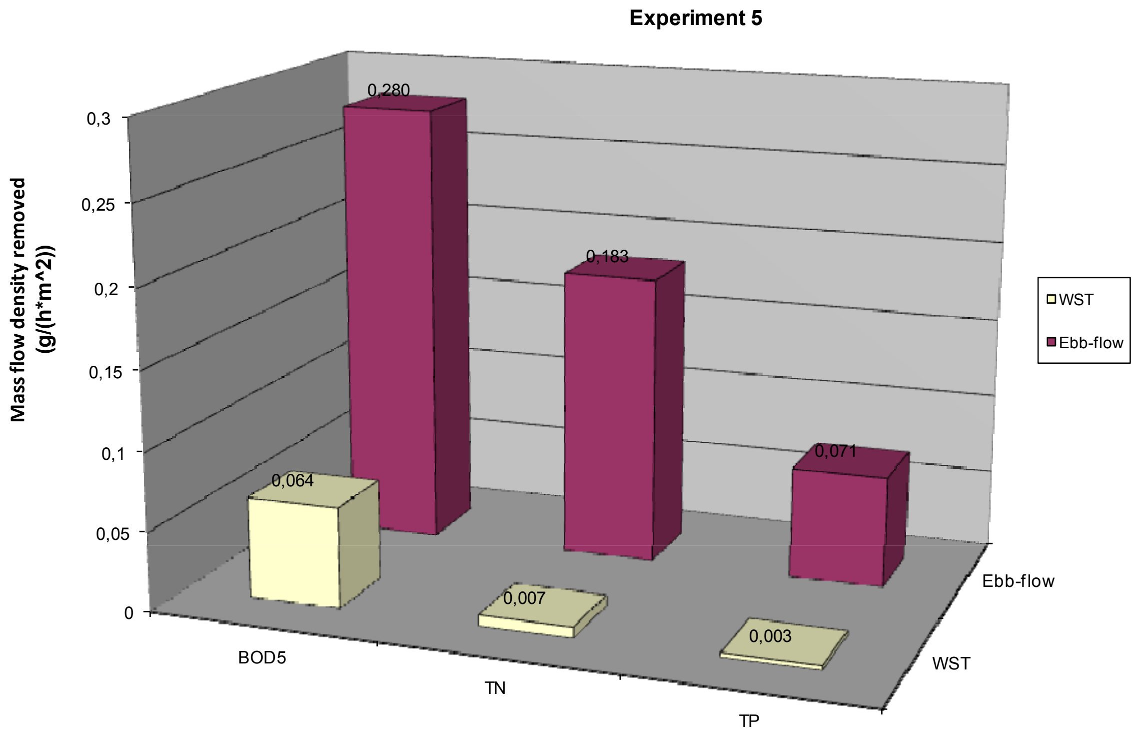
PICTURE 49. ϴ for different parameters and systems for experiment 2.



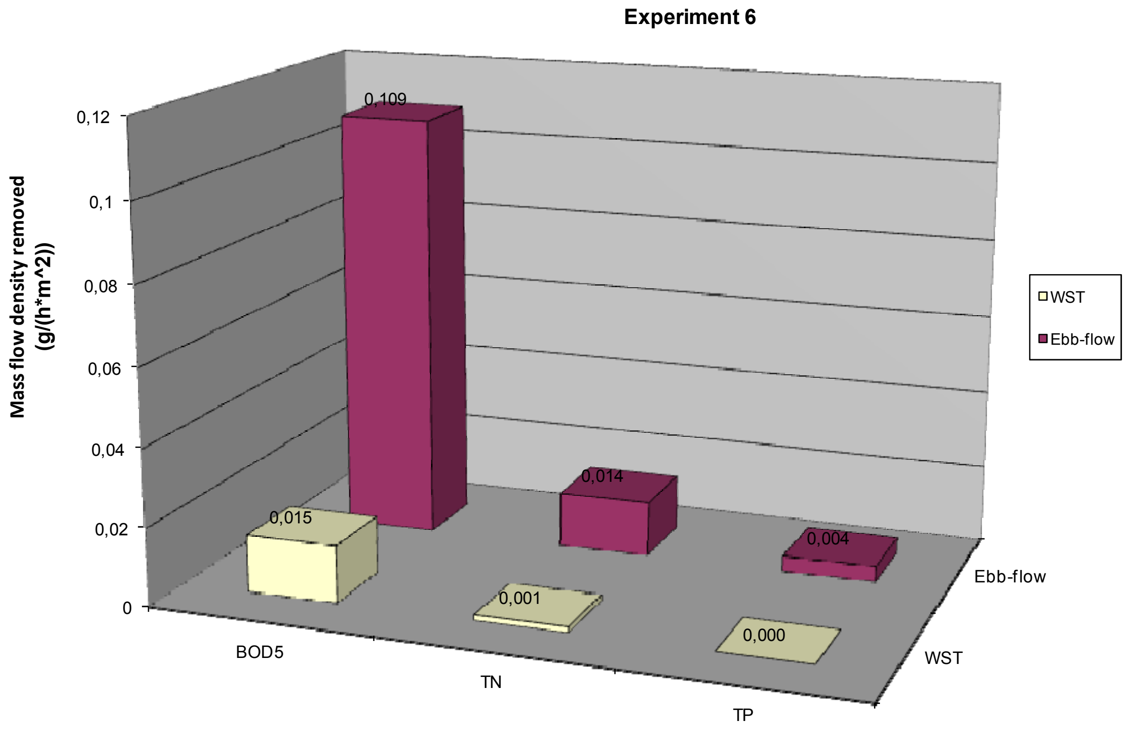
PICTURE 50. ϴ for different parameters and systems for experiment 3.



PICTURE 51. Θ for different parameters and systems for experiment 4.

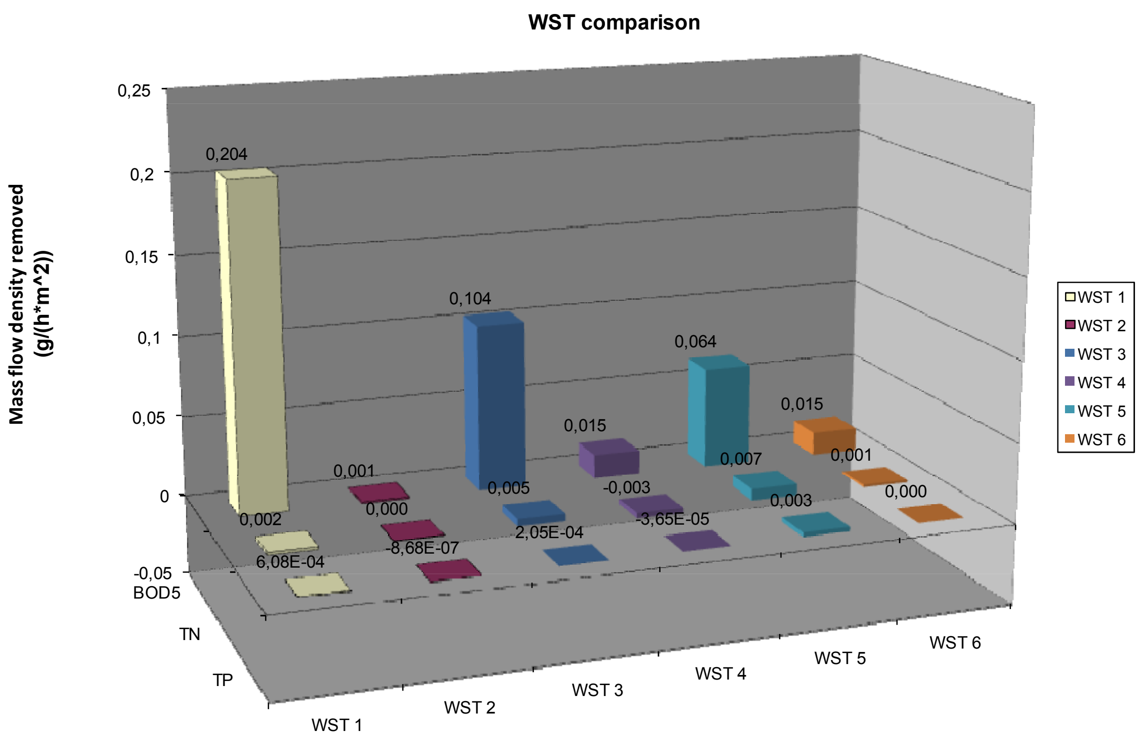


PICTURE 52. Θ for different parameters and systems for experiment 5.



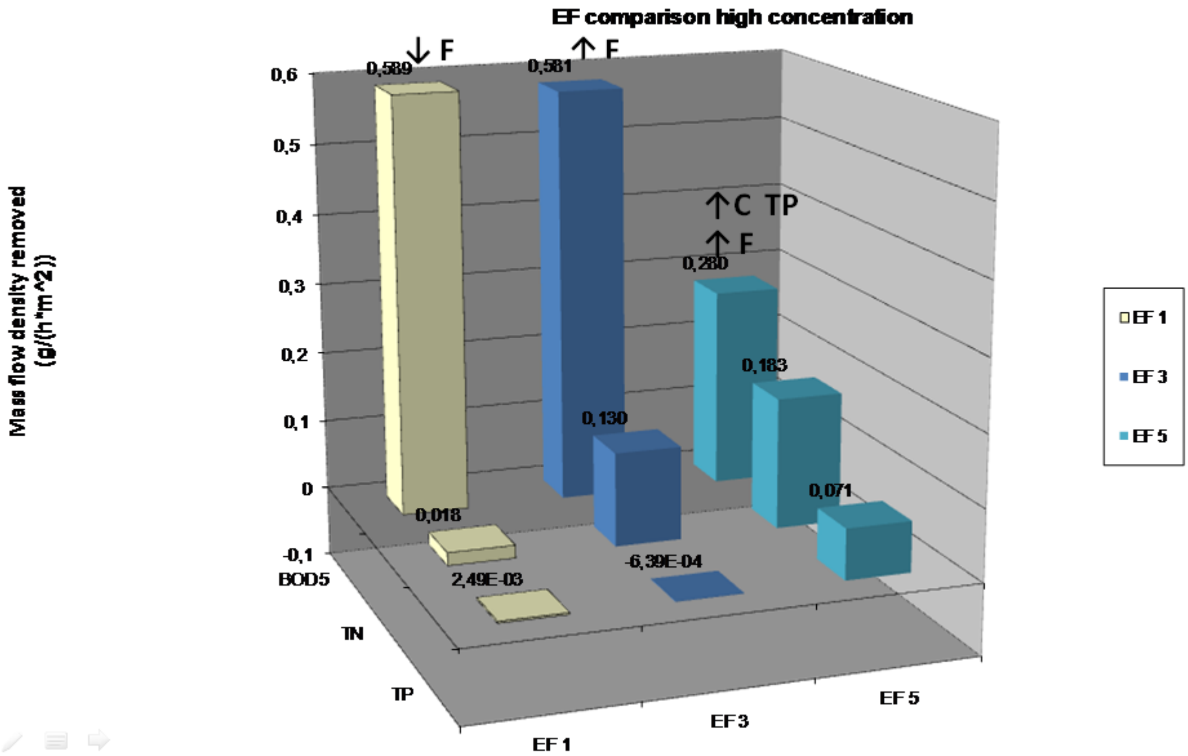
PICTURE 53. Θ for different parameters and systems for experiment 6.

All the Θ values for the WST are shown in Picture 54.



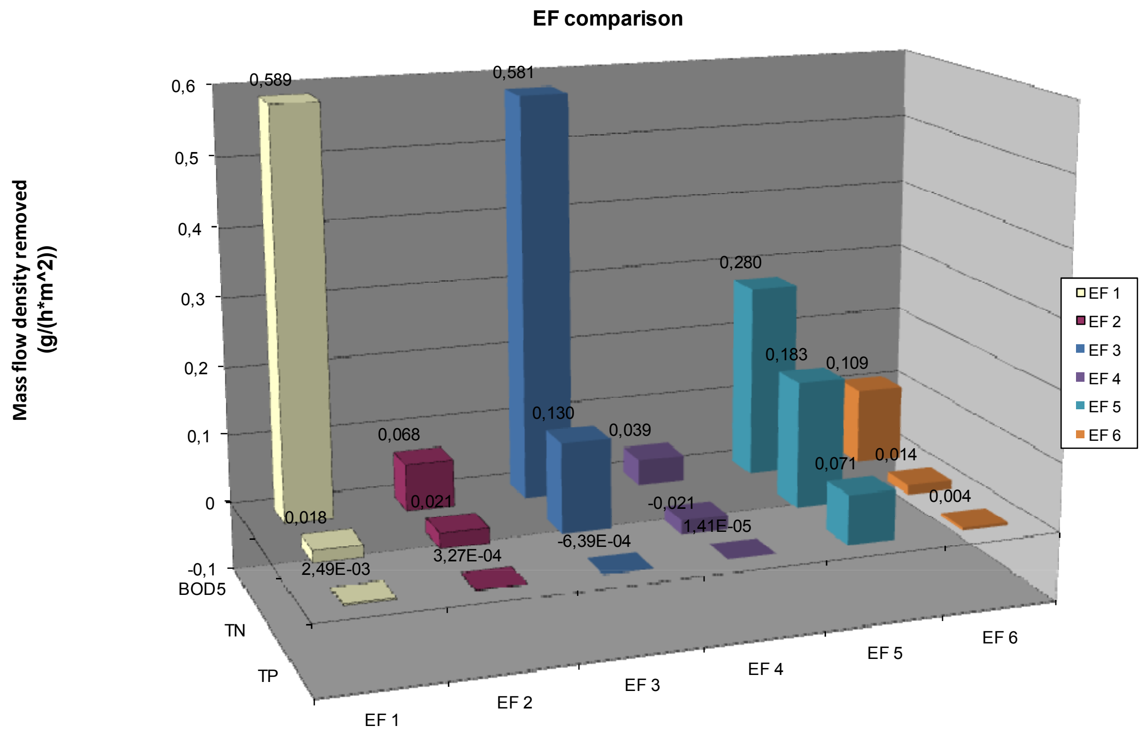
PICTURE 54. Θ for different parameters and experiments. (WST)

Best Θ values, at higher influent concentrations, for the WST are shown in Picture 55.



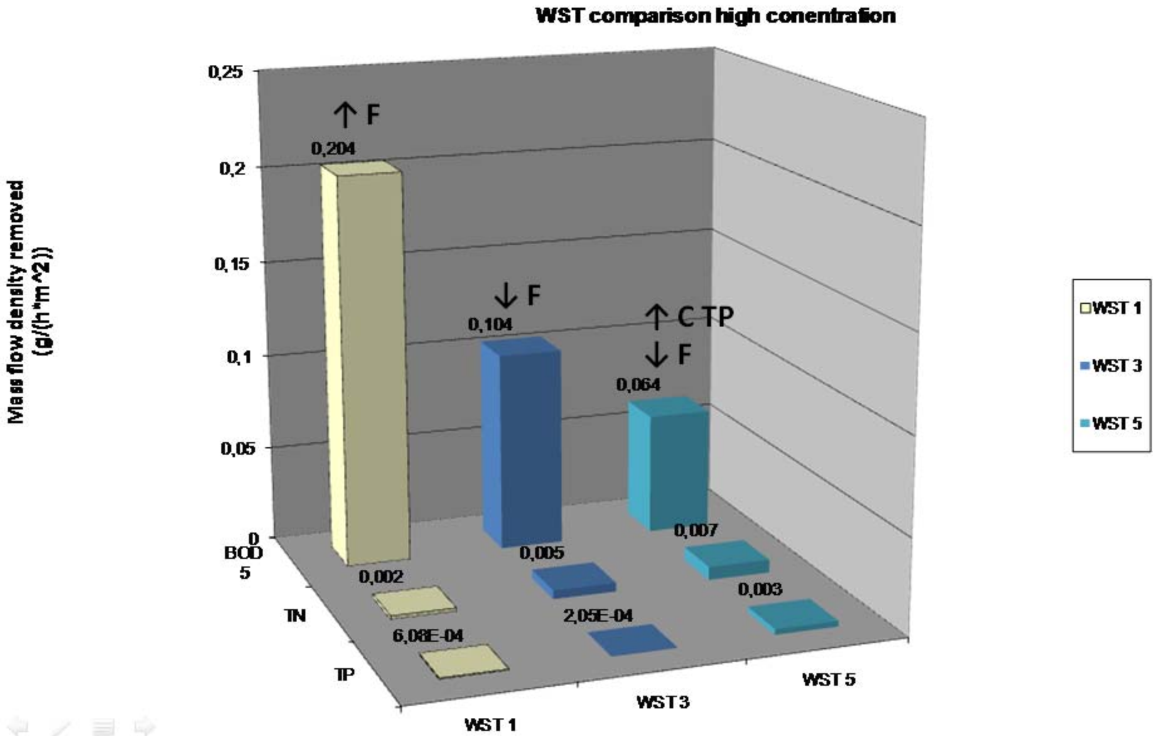
PICTURE 55. Θ for different parameters at higher influent concentration, EF.

All the Θ values for the EF are shown in Picture 56.



PICTURE 56. Θ for different parameters and experiments. (EF)

Best Θ values, at higher influent concentrations, for the EF are shown in Picture 57.



PICTURE 57. Θ for different parameters at higher influent concentration for (WST).

7. CONCLUSION AND DISCUSSION

7.1. Conclusions

During all the experiments and for both systems better removal values are obtained at higher initial influent concentrations. This result is very important if these systems want to be applied to leachate influent with high contaminant concentration.

If any of the parameters are in really low concentration in the influent, both systems do not work effectively. Best removal values of all experiments dealt in this final thesis is shown in table 12.

The values of Pälkäne willow stack tower and the pilot model of the greenhouse experiment were analyzed. Both WST systems can neutralize pH. The different contaminants removal values are compared in Table 12. The better values were obtained in Pälkane WST (Hepokorpi & Khelia, 2011).

TABLE 12. Best removal values for all experiments and comparison with Pälkäne Willow stack tower (Ruokola), 2010.

Removal	EF	WST Pilot plant	Pälkane WST
BOD5	16%	52%	82%
TN	35%	45%	76%
TP	41%	83%	75%

Willow stack tower and Ebb-flow systems have worked at different flow and willow area conditions in the different experiments, so the values have to be evaluated with mass flow density removal (ϴ), this parameter is explained in equation 10. In Table 13 to 17 the results are shown with this parameter. The values of Tables 13 to 17 show the removal efficiency calculated in percents concerning the results of all experiments completed in this final thesis testing process.

Ratio calculated as mass flow density removed (ϴ) between highest and lowest influent concentrations of TN and BOD_5 at different flow rates. Most significant values are shown below in Table 13.

TABLE 13. ϴ ratio between highest TN and BOD_5 concentration and lowest TN and BOD_5 concentration of treatment results.

Experiments \ Contaminants	ϴ ratio of highest and lowest concentration		
	BOD_5	TN	PO_4^-
Highest flow rate (EF)	756%	521%	NRHC
Lowest flow rate (EF)	1427%	NRLC	NRLC
Highest flow rate (WST)	1359%	-52%	NRLC
Lowest flow rate (WST)	9813%	NRLC	NRLC

NRHC	No influent contaminants removed at highest concentration
NRLC	No influent contaminants removed at lowest concentration
NS	No significant values (low values)

At different flow rate and systems, BOD_5 is removed better at higher influent concentration of TN and BOD_5. For different flow rate and systems, total phosphorus is removed better at higher influent concentration of TN and BOD_5, because at low concentration both systems can not remove TP. TN is removed better with higher influent concentration of BOD_5 and TN with the highest flow for the EF system. TN is removed better with lower influent concentration of BOD_5 and TN with the highest flow tested for the WST system.

Ratio calculated as mass flow density removed (ϴ) between highest and lowest flow rate for the EF system, most significant values are shown in Table 14:

TABLE 14. ϴ ratio between highest and lowest flow rate for EF system.

Experiments \ Contaminants	ϴ ratio between highest and lowest flow rate for EF		
	BOD_5	TN	PO_4^-
Highest influent c of TN and BOD_5	-1%	628%	NRHF
Lowest influent c of TN and BOD_5	76%	NRLF	NS

NRHF	No influent contaminants removed at highest flow
NRLF	No influent contaminants removed at lowest flow
NS	No significant values (low values)

At lower influent concentration of TN and BOD_5 for EF system, BOD_5 is removed better at higher flow rate; at higher influent concentration of TN and BOD_5 values are the same. At lower influent concentration of TN and BOD_5 for EF system, TN is not removed at lowest flow rate; at higher influent concentration of TN and BOD_5, TN is removed better at highest flow rate. TP is removed only at higher influent concentration of TN and BOD_5 and highest flow rate.

Ratio calculated as mass flow density removed (Θ) between highest and lowest flow rate for the WST system, most significant values are shown below in Table 15.

TABLE 15. Θ ratio between highest and lowest flow rate for WST.

Contaminants / Experiments	Θ ratio between highest and lowest flow rate for WST		
	BOD_5	TN	PO_4^-
Highest of c TN and BOD_5	-49%	162%	-66%
Lowest of c TN and BOD_5	1325%	NS	NS

NRHF	No influent contaminants removed at highest flow
NRLF	No influent contaminants removed at lowest flow
NS	No significant values (low values)

At lower influent concentration of TN and BOD_5 for WST system, BOD_5 is removed better at lowest flow rate; at higher influent concentration of TN and BOD_5 values are better at highest flow rate. At lower influent concentration of TN and BOD_5 for WST system, TN is not removed; at higher influent concentration of TN and BOD_5, TN is removed better at lowest flow rate. TP is removed better at higher influent concentration of TN and BOD_5 and highest flow rate.

Ratio calculated as mass flow density removed (Θ) between lowest influent PO_4^- concentration and highest influent PO_4^- concentration for WST and EF system. At highest influent concentration of TN and BOD_5 most significant values are shown below in Table 16.

TABLE 16. Θ ratio between highest and lowest PO_4^- concentration of treatment results.

Contaminants / Experiments	Θ ratio between highest and lowest flow rate for WST		
	BOD_5	TN	PO_4^-
Highest flow (EF)	-52%	41%	NRLC
Lowest flow (EF)	1505%	NRLC	NRLC
Highest flow (WST)	707%	NRLC	NS
Lowest flow (WST)	-39%	53%	1289%

NRHC	No influent contaminants removed at highest concentration
NRLC	No influent contaminants removed at lowest concentration
NS	No significant values (low values)

At higher flow for EF system, BOD_5 is removed better at lowest PO_4^- concentration; at lowest flow for WST system, BOD_5 is removed better at lowest PO_4^- concentration. At lowest flow for WST system, BOD_5 is removed better at lowest PO_4^- concentration. At higher flow for EF system, TN is removed better at highest PO_4^- concentration; at lowest flow for WST system, TN is removed better at highest PO_4^- concentration. At high and low flow rate for EF system, PO_4^- is not removed at lowest PO_4^- initial concentrations. At lowest flow rate for WST, PO_4^- is removed at highest PO_4^- initial concentration.

Proportion calculated as ϴ EF/ WST system, values are shown below in Table 17.

TABLE 17. ϴ proportion EF/WST.

Contaminants / Experiments	ϴ proportion between EF/ WST		
	BOD_5	TN	PO_4^-
Experiment 1	2.9	10.3	4.1
Experiment 2	64.5	NRWST	NS
Experiment 3	5.6	28.7	NREF
Experiment 4	2.6	NS	NRWST
Experiment 5	4.4	26.5	24.9
Experiment 6	7.4	9.6	134.9

NRWST	No contaminants removed with Willow stack Tower
NREF	No contaminants removed with Ebb-flow system
NS	No significant (low values)

Always ϴ results are higher with the EF system than the WST.

If the system is missing one of these parameters, bacteria start to self digest. The efficiency of TN removal depends on TP concentration.

Summary of the results

In different conditions and system, removal yield of different compounds best removal values can be seen in Table 18 and Table 19. These tables are shown below.

TABLE 18. Best result for mass flow density removed at different conditions and different parameters for EF.

Conditions / ϴ	EF		
	Highest c BOD_5 and TN	Highest flow	Highest c TP
BOD_5 removed	BCRR	Same value	WCRR
TN removed	BCRR	BCRR	BCRR
TP removed	BCRR	No significant	BCRR

TABLE 19. Best result for mass flow density removed at different conditions and different parameters for WST.

Θ \ Conditions	WST		
	Highest c BOD_5 and TN	Highest flow	Highest c TP
BOD_5 removed	BCRR	BCRR	WCRR
TN removed	BCRR	WCRR	BCRR
TP removed	BCRR	BCRR	BCRR

BCRR	Best contaminants removal results
WCRR	Worst contaminants removal results

7.2. Emission limits for landfill leachate in Europe

In European legislation, there are no uniform emission limits for landfill leachate. Several chemical and physical parameters are summarized in Table 19 for the member countries Netherlands, Spain, Austria, Germany and Italy.

All of these countries make distinctions between direct emission to a river/lake/sea and indirect emission, which means further treatment of pre-cleaned leachate in communal wastewater works. Looking at Table 20 it becomes obvious that the limits and parameters are quite different. (Dahm, Kohlbach, 2000).

TABLE 20. Best result at different conditions and parameters.

Parameter	Units	Germany		Austria		Netherlands		Spain		Italy	
		direct-introduction	indirect-introduction	direct-introduction	indirect-introduction	direct-introduction	indirect-introduction	direct-introduction	indirect-introduction	direct-introduction	indirect-introduction
Temperature	ºC	-	-	-	-	-	-	-	-	-	-
pH		-	-	6.5-8.5	6.5-9.5	6.5-9.0	6.5-9.0	5.5-9.5	-	5.5-9.5	-
Conductivity	µS/cm	-	-	-	-	-	-	-	-	-	-
Suspended Solids	mg/l	-	-	20	-	-	-	80	-	-	-
COD	mg/l	200	-	50	-	100	-	160	-	125	-
BOD_5	mg/l	20	-	10	-	20	-	40	-	25	-
Hydrocarbons	mg/l	10	-	5	15	-	-	-	-	-	-
Aldehyde	mg/l	-	-	-	-	-	-	1	-	-	-
Detergent	mg/l	-	-	-	-	-	-	2	-	-	-
Pesticidal	mg/l	-	-	-	-	-	-	0.05	-	-	-
Oil-fat	mg/l	-	-	-	-	-	-	20	-	-	-
SO_4	mg/l	-	-	-	-	-	-	2000	-	1000	-
Chloride	mg/l	-	-	-	-	-	-	2000		1200	-
Arsenium	mg/l	0.5	0.5	-	-	0.05	0.03	0.5	-	-	-
Lead	mg/l	0.5	0.5	0.5	0.5	-	-	0.2	-	-	-
Cadmium	mg/l	0.1	0.1	0.1	0.1	0.0025	0.005	0.1	-	-	-
Chromium	mg/l	0.5	0.5	0.5	-	-	-	-	-	-	-
Kopper	mg/l	0.5	0.5	0.5	0.5	-	-	0.2	-	-	-
Mercury	mg/l	0.05	0.05	0.01	0.01	0.005	0.0025	0.05	-	-	-
Zinc	mg/l	2	2	0.5	0.5	-	-	1	-	-	-

7.3 Discussion

Both systems work better at higher influent leachate concentration, so it is a good option to introduce these systems at the beginning of the process for complex leachate treatments. In Table 21 are shown the differences between small scale plants of WST and EF and their properties.

TABLE 21. Characteristic comparison between small scale plant of WST and EF.

Characteristic	WST Scale Plant	EF
Efficiency per Flow & Area	HIGHER	LOWER
% nutrients removal	HIGHER	LOWER
Equipment size	HIGHER	LOWER
Pumping consumption	HIGHER	LOWER
Evaporation	HIGHER	LOWER
System complexity	LOWER	HIGHER
Insulation possibility	DIFFICULT	EASY

If the leachate has not got enough concentration, recirculating effluent from a settler is a good option. In this way the leachate can get a higher influent concentration. The diagram with settler configuration, for a leachate treatment is shown in Figure 11:

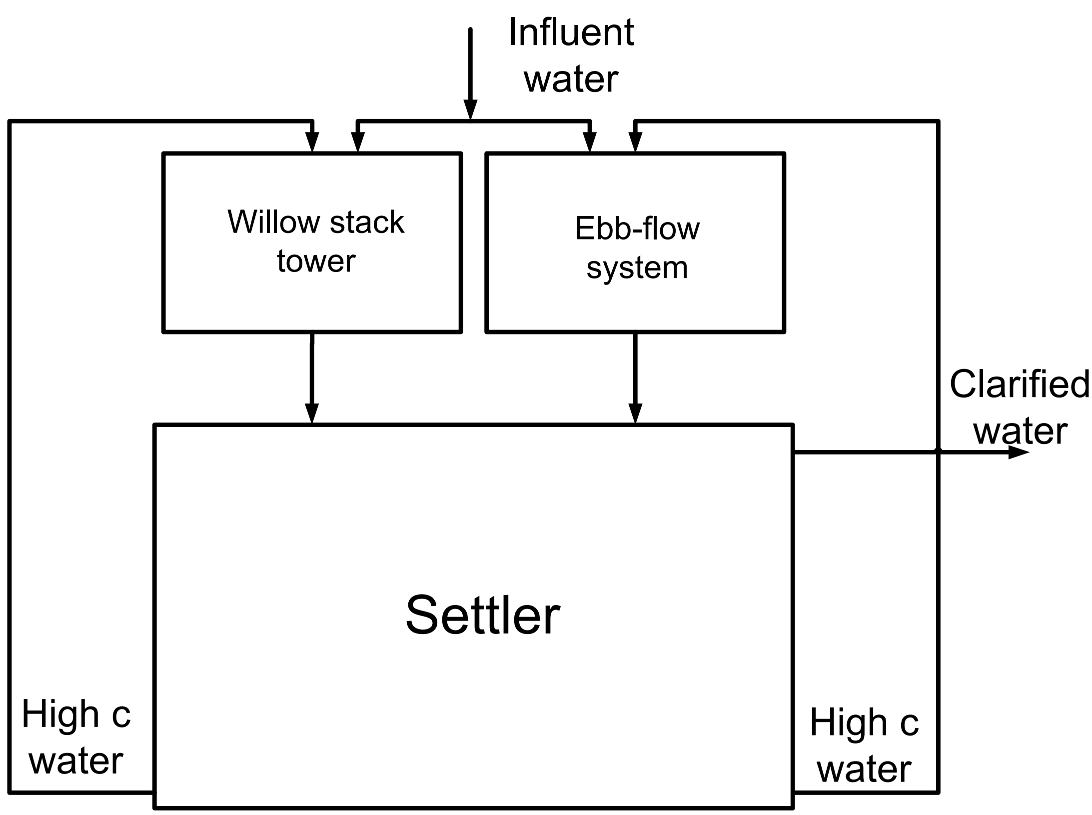


FIGURE 11. Diagram with settler configuration.

7.4 Didactic method

This project can be exploited for environmental engineering students, to see how a practical biochemical process works. Microbiology students can benefit this project full of life, for example algae, bacteria, larva, worms, flies, plants. The hydrodynamics force transformation with the siphon, and it can be used for showing how the potential force can be transformed into kinetic force.

During this project a new analytical method for analysing Total Nitrogen with HACH Lange instrument has been applied in TAMK laboratories. This method can be exploited also for other students. See Appendix 3.

7.5 Continuation of the project

This project research should be continued. Higher influent concentrations than in this project, for both systems and more parameters should be tested so that sulphur, potassium and heavy metal concentrations could also be analysed. In Ebb-flow system, flow rate could be increased. For the WST it is stoöö a good idea to test higher and lower flow rates.

8. PROCESS MAINTENANCE

From the processes point of view it is important to pay attention to a proper maintenance. During the implementation of the system there were two small incidents. The most significant incident was a long lasting leak in silicone tubing (P5). This hose was leaking sometimes; the first time the leak was because the hose was excessively worn, the second was due to the stiffness of the hose. The final solution is to set a silicone hose of larger diameter and more flexible. In Picture 58 and 59 wear hose and pool caused by leakage can be seen.

PICTURE 58. Wear hose.
(Photo: Alberto Freire, 2011)

PICTURE 59. Pool caused by leakage.
(Photo: Alberto Freire, 2011)

The other notable incident is the obstruction of the outlet pipe of the biofilter (BF 2). This incident happened because the concentration of contaminants in the waste water was high. This kind of problem can be solved with a weekly maintenance. This maintenance includes cleaning the pipe and hose, with clean and pressured water; peristaltic pump (P2) and check the cleanliness of the centrifugal pump (P1), which being submerged much dirt accumulates over the surface. Centrifugal pump maintenance is shown in Picture 60 and 61.

PICTURE 60. Centrifugal pump after two weeks working. (Photo: Alberto Freire, 2011)

PICTURE 61.Cleaning maintenance. (Photo: Alberto Freire, 2011)

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APPENDIX 1: MATERIAL SAFETY DATA SHEETS

Disodium tetraborate: http://avogadro.chem.iastate.edu/MSDS/borax.htm

Phosphoric acid: http://www.sciencelab.com/msds.php?msdsId=9927393

Potassium persulphate: http://www.sciencelab.com/msds.php?msdsId=9927234

Sodium azide: http://www.sciencelab.com/msds.php?msdsId=9927588

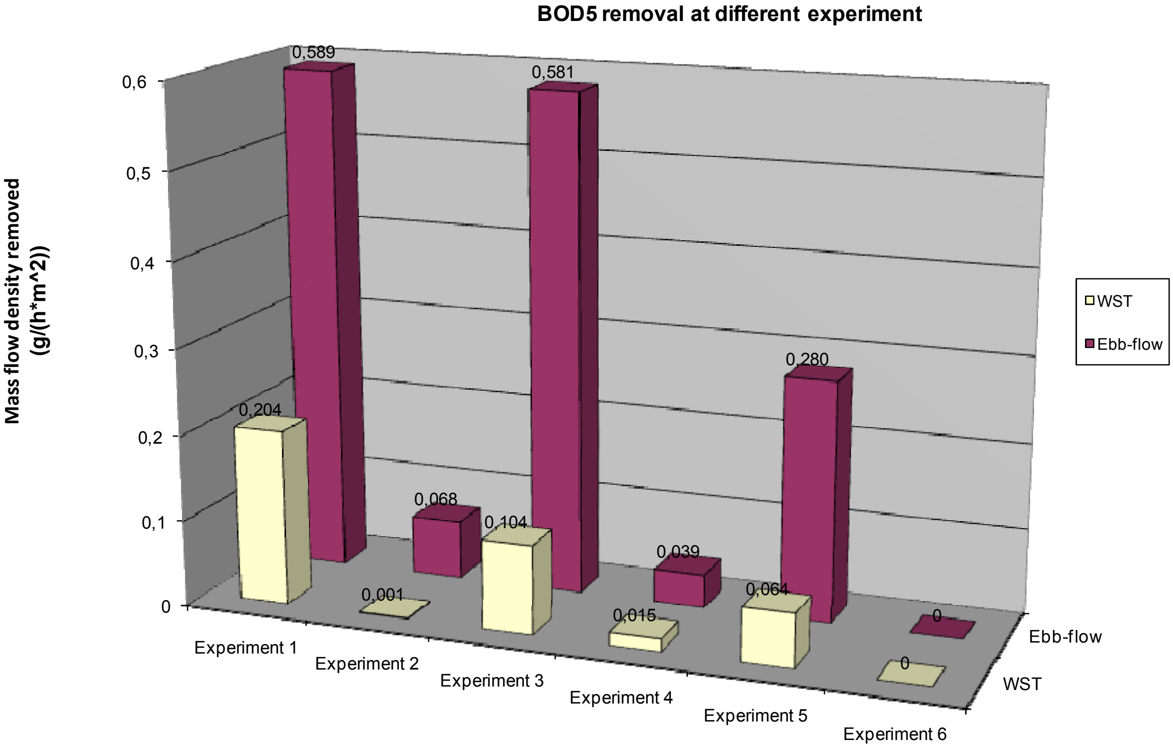
Sodium hydroxide: http://www.sciencelab.com/msds.php?msdsId=9924999

Sulphudric acid: http://www.jmloveridge.com/cosh/Sulphuric%20Acid.pdf

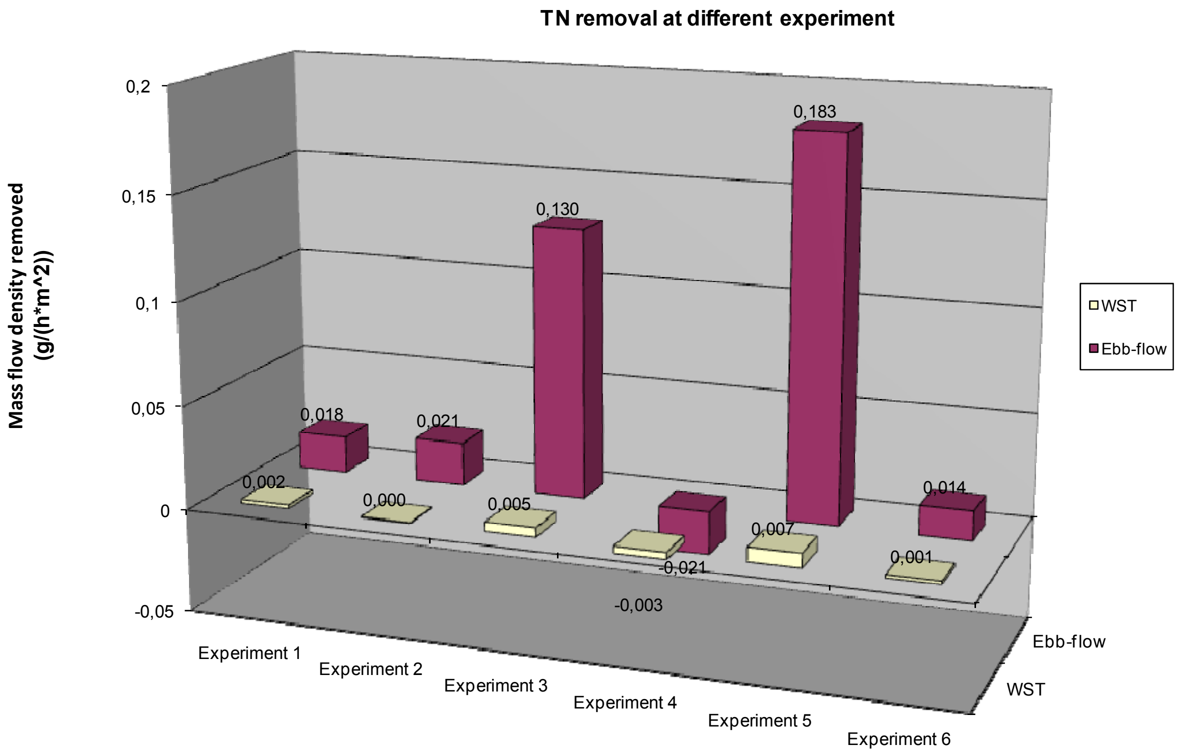
2-propanol: http://www.carolina.com/text/teacherresources/MSDS/2propanol7.pdf

APPENDIX 2: EXTRA CALCULATIONS

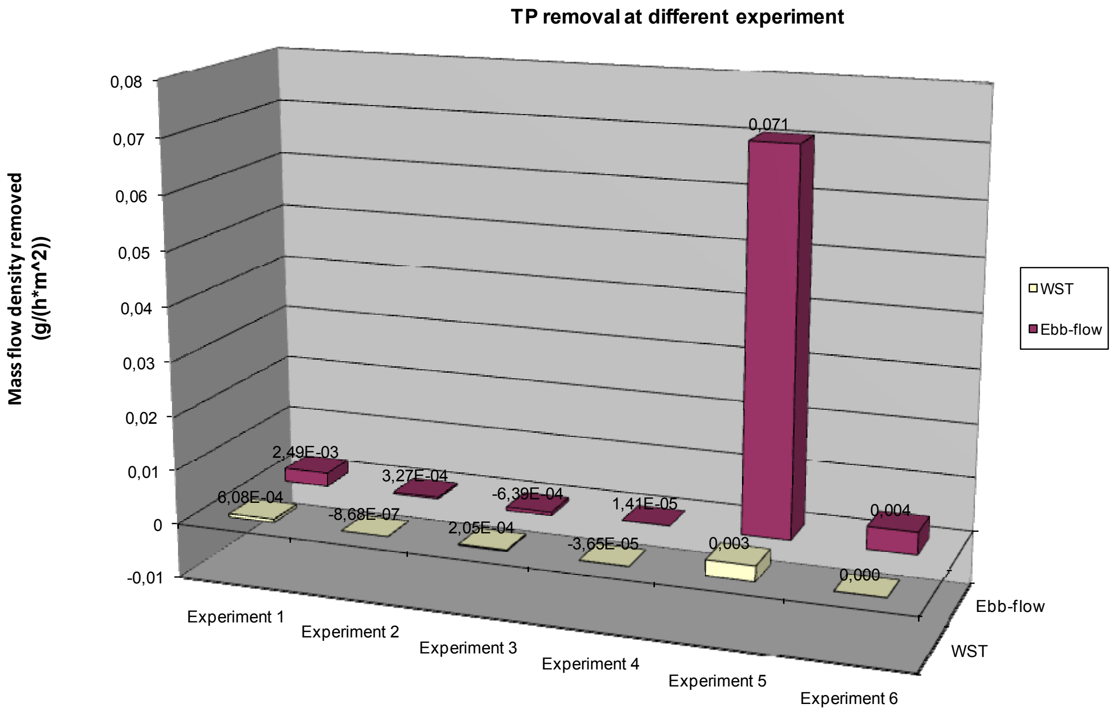
Extra diagrams:



PICTURE 62. Θ for BOD_5 at different experiments and systems.

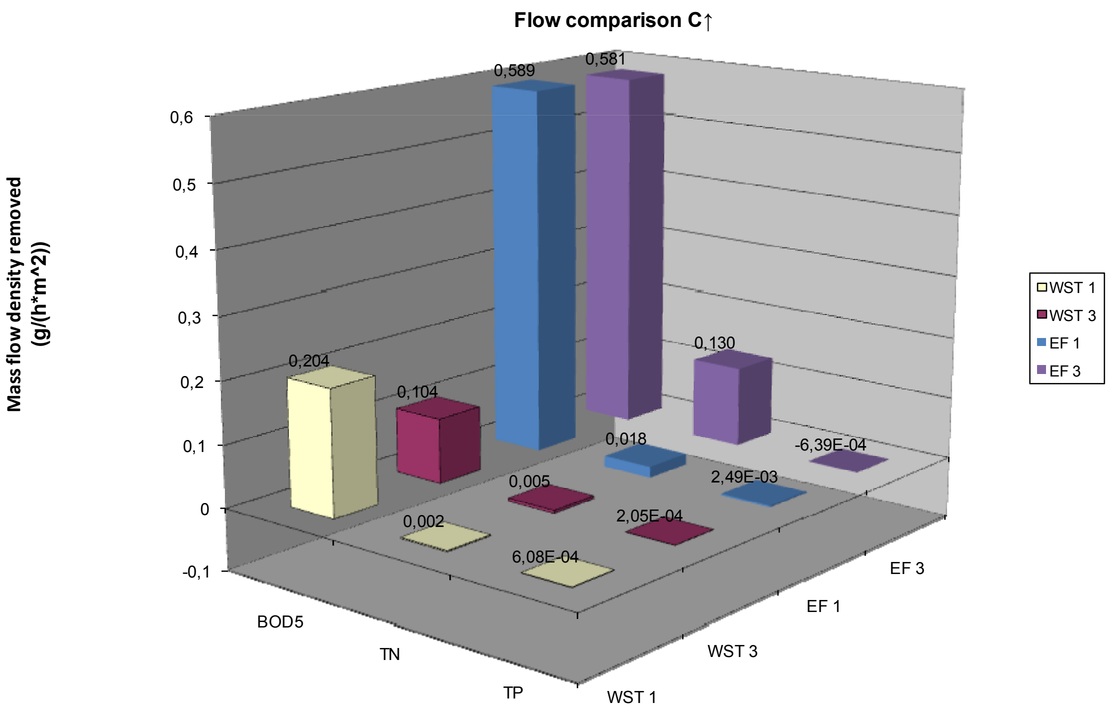


PICTURE 63. Θ for TN at different experiments and systems.

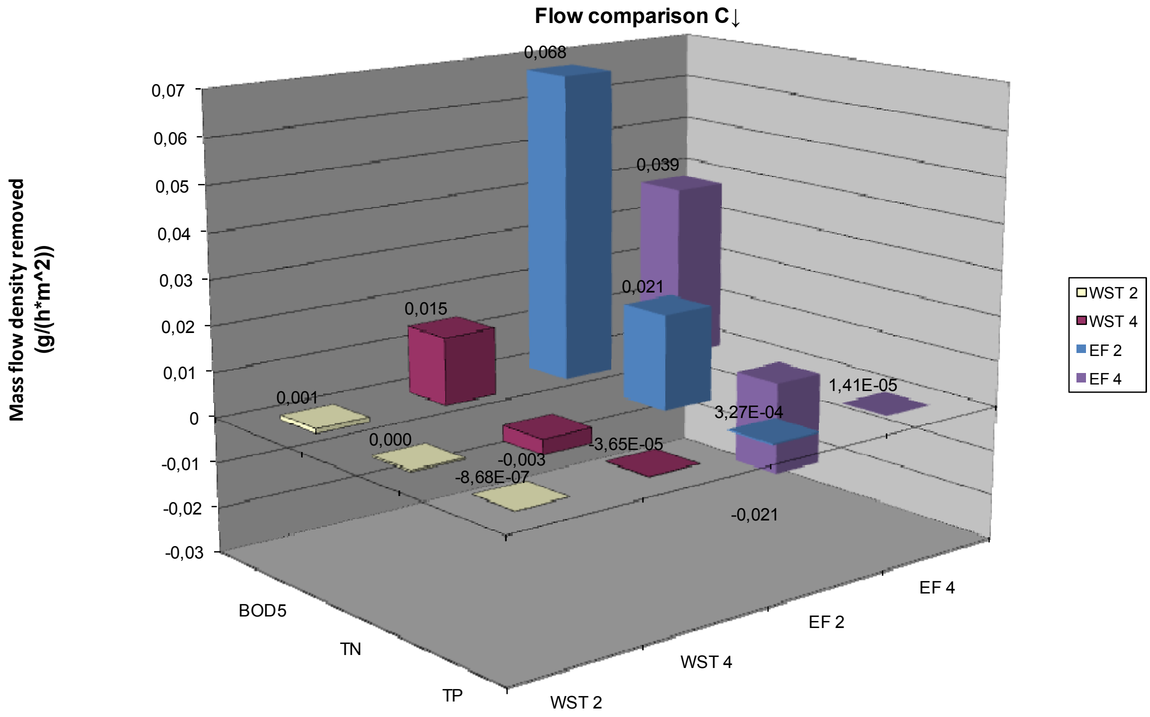


PICTURE 64. Θ for TP at different experiments and systems.

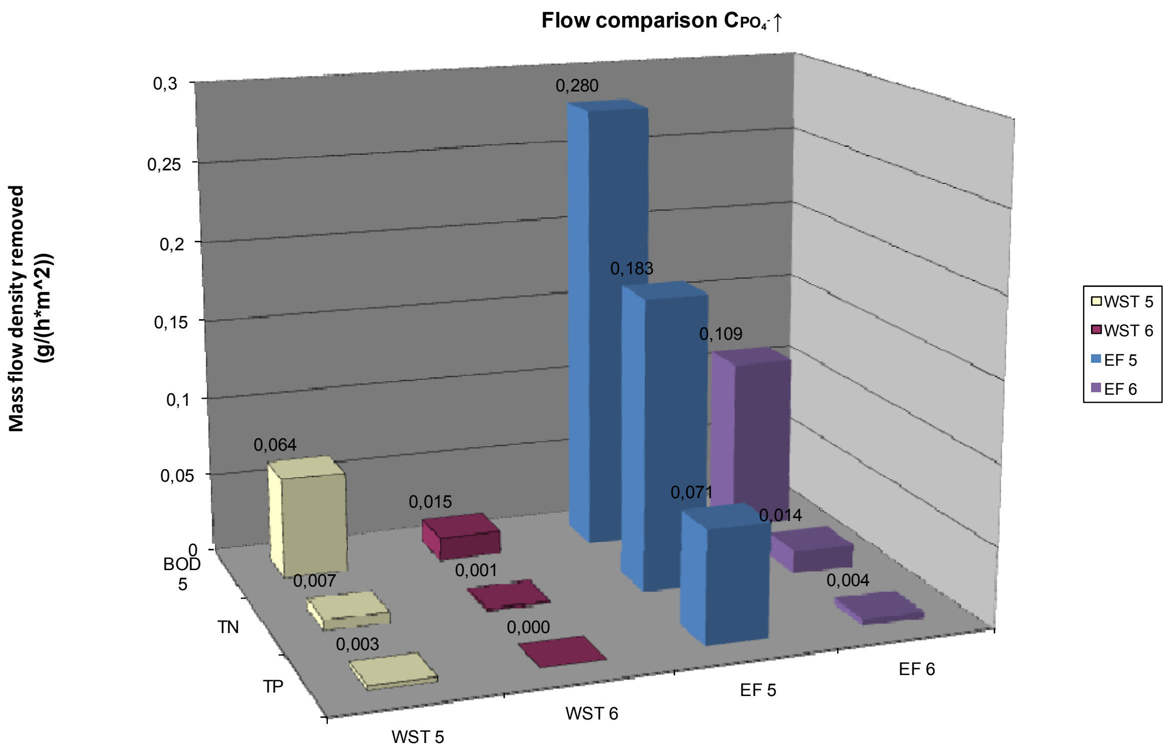
Comparing experiments with two same parameters and one different, plots are obtained.



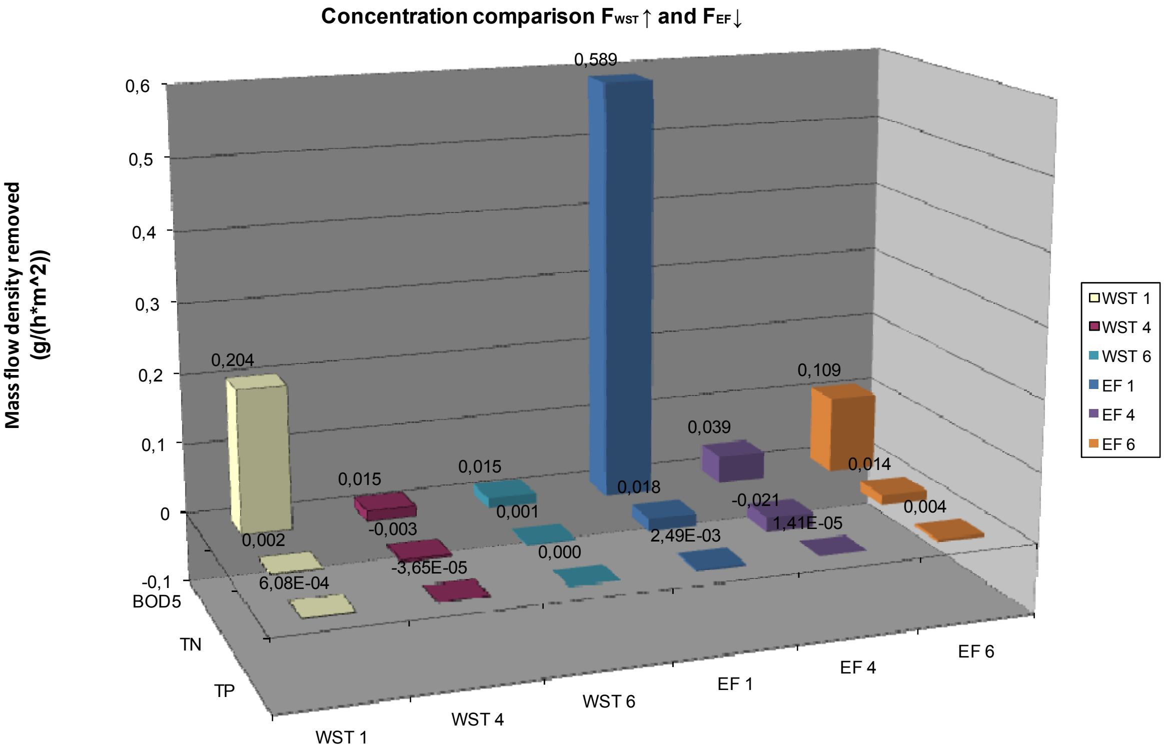
PICTURE 65. Θ flow comparison c↑.



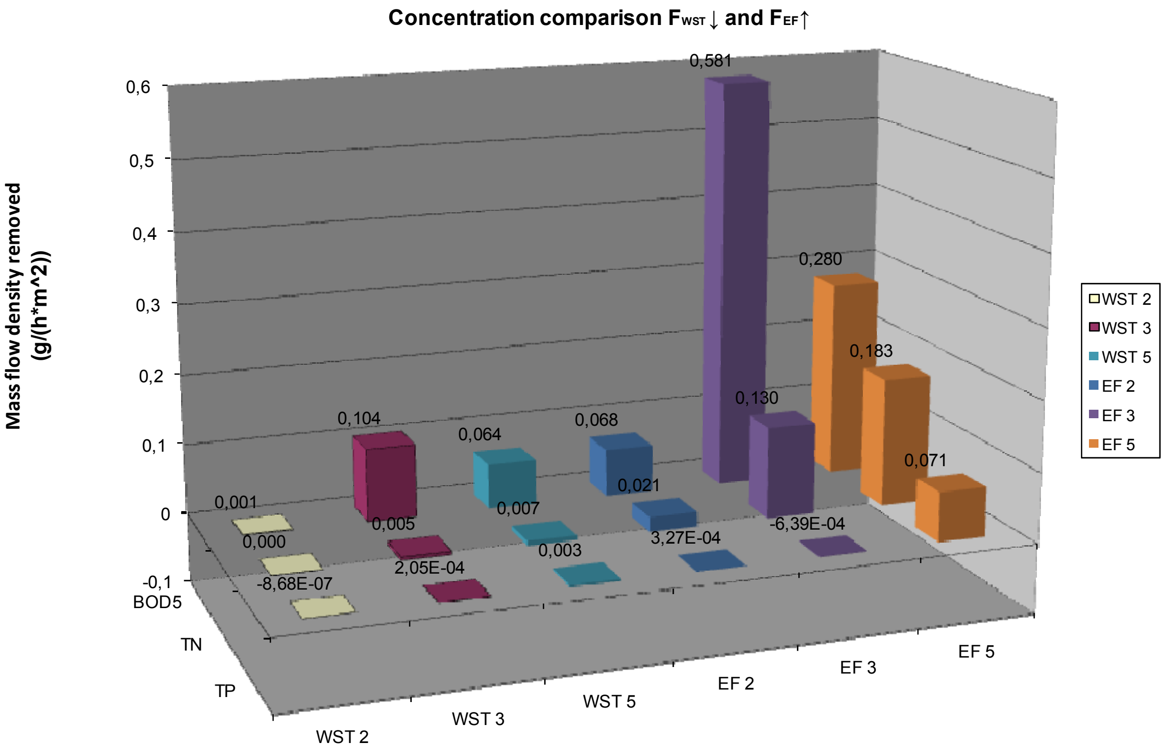
PICTURE 66. Θ flow comparison c↓.



PICTURE 67. Θ flow comparison c_{PO4}↑.



PICTURE 68. ϴ Concentration comparison F_{WST}↑ and F_{EF} ↓.



PICTURE 69. ϴ Concentration comparison F_{WST} ↓and F_{EF} ↑.